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Impacts of the Jones Act on the Alaska Forest Products Trade

Kristine C. Jackson and Charles W. McKetta

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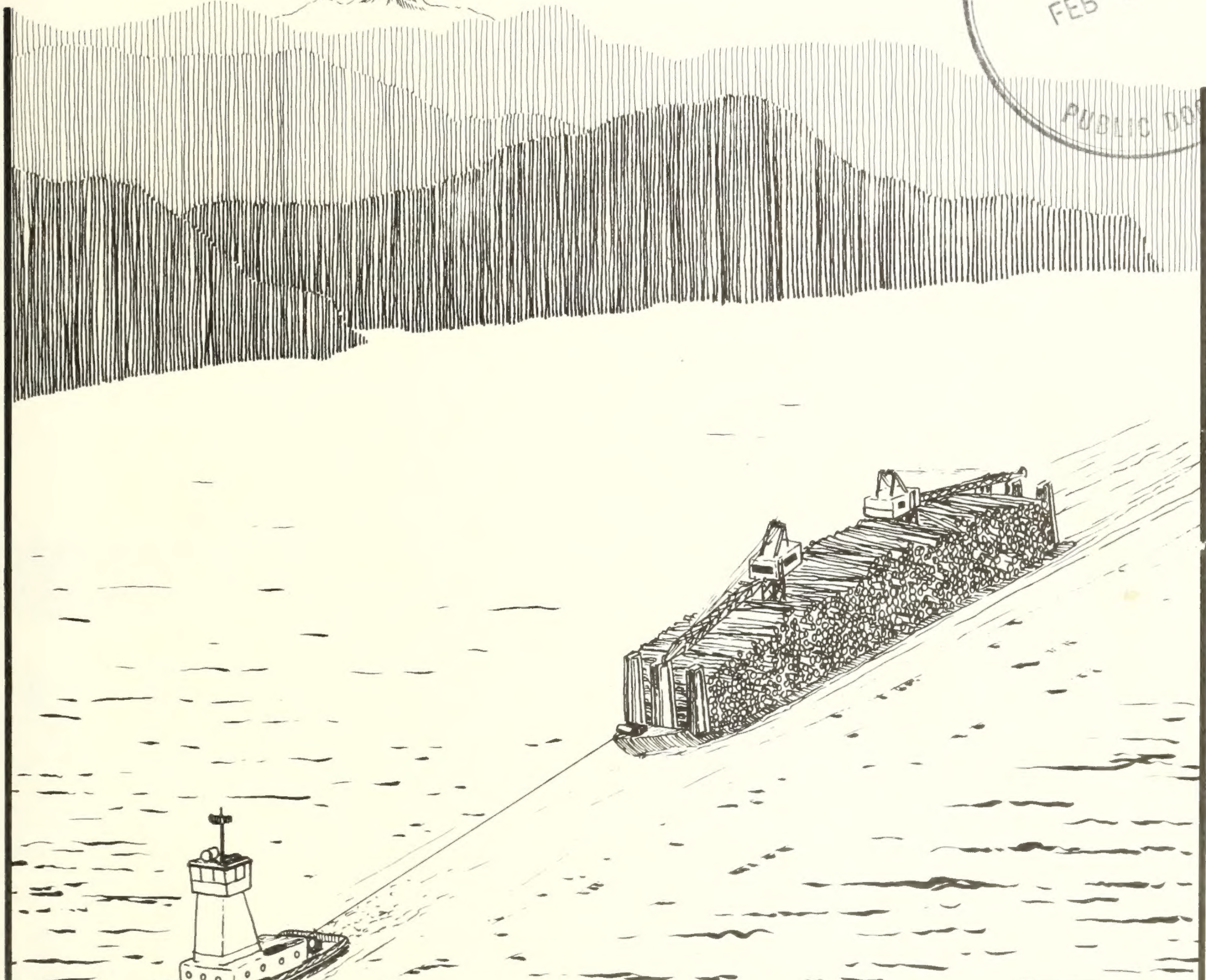

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Abstract

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Alaska forest products trade flows for 1982 were studied to determine the effects of the Merchant Marine Act of 1920 (the Jones Act). Information was collected from timber producers, forest product industries, and waterborne shippers in Alaska, British Columbia, and the Pacific Northwest. Trade flows were simulated, using a partial equilibrium model based on resource rents, with and without the Jones Act restrictions.

Results indicate that $4.77 million in additional costs were incurred in 1982 because of the Jones Act. These effects appeared small, however, relative to the wholesale value of trade. Further, the Jones Act cost differential was not a major factor in market determination, although low-value products and longer trade routes were more sensitive to cost changes. Primary movements of logs and chips and lumber imports from the Pacific Northwest showed the greatest potential for cost savings after relaxing the Jones Act.

Keywords: Jones Act, trade balance, markets (external), forest products carriers, economics (forest transport), Alaska (southeast), southeast Alaska.

Summary

Movements of Alaska forest products are dependent on waterborne transportation systems because of the State's location and geography. The Merchant Marine Act of 1920 (the Jones Act) restricts waterborne shipments between U.S. ports to vessels built and registered in the United States. The goal of this study was to assess the effects of the Jones Act on Alaska forest products trade. This included measuring forest product trade flows and determining the economic impact of the Jones Act on timber producers, consumers, and shippers in Alaska. Specific objectives were to examine the size of the Jones Act freight rate differentials; the effects of the rate differentials on trade flows; and the effects on the wealth of forest resource owners and forest products consumers in Alaska.

Three analytical tools were used. First, Jones Act freight rate differentials were calculated by calibrating 1982 shipping rates to indices of U.S. construction and maintenance costs as imposed by the Jones Act. Relaxing of the Jones Act was simulated by calculating the expected decreases in domestic freight rates, thus causing a corresponding increase in resource rents. Second, models of the southeast Alaska forest products trade flows were developed. F.O.B. product prices represented the resource rent values of timber resources. Constraints on supply, demand, and individual movements were used to simulate actual 1982 market conditions. Using a model of internal log transfers and a derived-demand, partial-equilibrium model, effects on both coastwise and internal southeast Alaska forest products trade were estimated. Finally, these changes in costs were used in an input-output simulation of the southeast Alaska economy using the *Interactive Policy Analysis Simulation System* to estimate the indirect and induced effects.

The direct effect of the Jones Act was a reduction in income for 1982 for Alaska forest resource owners and consumers of forest products that totaled $4.77 million. Freight differentials ranged from under $2.00/MBF to over $13.00/MBF for the domestic routes, which indicated that protection of domestic shipping did have an adverse effect on Alaska forest products trade in 1982. Relaxing the Jones Act did not cause shifts in trade flows for most products. As transportation costs to the Pacific Northwest decreased, lower value products showed greater sensitivity to shift in market destinations. Pulpwood was the only product to actually shift direction, but spruce and hemlock cants and wood chips would be the next to shift with additional changes in transportation costs.

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Introduction

Forest products is one of several predominant natural resources industries in Alaska. This industry is concentrated in southeast Alaska. In our study year, 1982, 563 million board feet (MMBF) of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) was harvested in this region and sold as export logs, lumber and cants, dissolving and sulphite pulps, pulpwood, and wood chips. Pacific Rim countries typically purchase 95 percent of Alaska forest products, with Japan taking over 90 percent. About 4 percent is shipped to the Pacific Northwest and the remainder is consumed in-State. In addition, 193 MMBF of building supplies were barged from the Pacific Northwest to Alaska in 1982.

The dependence of Alaska on waterborne transportation systems has raised a number of questions. These concern how restrictions in the Jones Act[1] affect U.S.-built and crewed U.S.-flag vessels in this trade. A number of shippers allege that all waterborne trade between Alaska and the lower 48 States incurs higher shipping costs, and the costs are partly a result of the Jones Act. This may have helped to shape current Alaska trade patterns; however, the effects of the Jones Act on Alaska forest products trade have not been substantially addressed in previous studies.

In this report, we examine the proposition that the Jones Act limits trade from Alaska to the lower 48 States. Measurement of freight rate differentials and measurement of the impact on trade routes were the major goals of this study. Specific objectives were:

1. To determine the differences between freight rates for equivalent vessels under U.S. and foreign flags and to measure these differences for the Alaska forest products trade by product, route, and transportation mode.

2. To determine the effect that Jones Act differentials have on the direction of trade between foreign and domestic destinations.

3. To measure the potential monetary losses for Alaska timber resource owners and forest products consumers caused by the Jones Act.

This three-step analysis provided a useful basis for discussing the Jones Act, for identifying the shipping modes and forest products that are most affected, and for approximating the cost of the Jones Act to Alaska in 1982.

Alaska Forest Products Trade

The coastal rain forest of southeast Alaska is the northern extension of the rain forests of Oregon, Washington, and British Columbia. Western hemlock comprises 68 percent of this forest type, Sitka spruce 27 percent, and cedar (*Chamaecyparis* sp.) about 5 percent (University of Alaska 1964). In southeast Alaska, Sitka spruce is the dominant lumber species, and western hemlock is used primarily in the production of high-grade dissolving pulp.

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[1] For convenience, a glossary adapted from Long and Blattner (1985), is provided at the end of this paper. Definitions of unusual terms used in this report are included.

Of the 5.6 million acres of commercial forest land in southeast and south-central Alaska, about 5.1 million acres are in the Tongass and Chugach National Forests. Much of the remainder is in State and private ownership, although a small area is under Bureau of Land Management jurisdiction. The Bureau of Indian Affairs manages timber on the Annette Island Indian Reservation. By 1984, 464,605 Federal acres were transferred to Native Corporations under the Alaska Native Claims Settlement Act of 1971 (ANSCA) (Mehrkens 1983). Most ANSCA lands are of high commercial value and were selected from the Tongass National Forest.

Timber harvests for southeast Alaska are summarized in table 1. The Tongass National Forest provides most of the volume harvested and averages 337 MMBF per year. State timber harvests have been relatively constant since 1980 and average 5.3 MMBF. Since the land transfers to Native Corporations began, these harvest levels have increased from 70.3 MMBF in 1980 to an average annual cut of 214 MMBF since 1982 (Mehrkens 1985).

Due to federal primary manufacturing requirements, most of the National Forest timber is manufactured into cants or high-grade dissolving pulp. The balance is sawn into dimension lumber or is chipped. Between 80 and 85 percent of the Native Corporations timber harvest is exported unprocessed.

Table 1—Timber harvests in southeast Alaska by ownership, 1980-84

Ownership	1980	1981	1982	1983	1984
			MMBF, log scale 1/		
Forest Service (Tongass NF)	452.1	385.7	344.9	251.2	249.8
State of Alaska	5.1	5.4	5.7	5.6	4.7
Native Corporations 2/	70.3	122.0	209.2	232.0	202.0
BIA/Annette Island	15.3	2.5	2.5	3.2	.7
Total	542.8	515.6	562.7	492.0	457.2

1/ Includes utility volume.

2/ Native Corporation production is expected to fluctuate in response to different marketing strategies and changing demand. Estimates range from 150 MMBF per year at a sustained yield level to 225 MMBF using intensive management practices.

Source: Mehrkens 1985.

The major Alaska products are logs; pulpwood; green-sawn lumber, cants and waneys; wood chips; and high-grade dissolving pulp. Production is concentrated in the southeast region and accounts for 32 percent of total regional primary employment (Sandor 1981) and 78 percent of the State's lumber and paper products work force (USDA Forest Service 1982). Of the 208 sawmills in operation in 1982, Clark (1983) estimates that southeast Alaska mills have 74 percent of the sawmill capacity in Alaska, with a saw-log capacity of 365 MMBF per year and an annual woodchip capacity of between 230,000 and 315,000 metric tons (MT). Production in southeast Alaska has not approached capacity for several years because of poor conditions in major markets, most notably Japan. During 1982, 60 percent of the logs were reduced to pulp and 40 percent were sawn as poor market conditions reversed the usual ratio for saw logs to pulpwood (Development Planning and Research Associates 1983).

Alaska's main advantage in international trade is its location relative to the Pacific Rim markets. Figure 1 shows the comparative advantage Alaska has in domestic and foreign trade. Primary trading partners are few in number: Japan, Canada, India, People's Republic of China, The Republic of China (Taiwan), and the Republic of Korea together account for nearly two-thirds of Alaska's imports and exports in all sectors. Overall, Japanese markets account for 95 percent or more of all forest products exported from Alaska, but the recent removal of trade restrictions between the United States and the People's Republic of China has opened new markets for Alaska timber producers. Rapid growth and industrialization in China, Taiwan, Korea, Indonesia, and other Pacific Rim countries indicate rising demand for forest products in these regions (Jackson 1983).

A small volume of wood products is shipped to the lower 48 States each year. This trade mostly consists of high-valued products, such as high-quality, music-grade Sitka spruce logs and cants, and dissolving pulp. Several institutional factors, including the Jones Act, are alleged to limit entry to domestic markets in the lower 48 States (USDA Forest Service 1982).

Less than 1 percent of the reported 1982 wood products consumption in Alaska was produced within the State. This figure may be slightly higher because of small-volume, unreported sawmills, mostly in interior Alaska. Both imported kiln-dried lumber from British Columbia and the Pacific Northwest and locally produced lumber from the interior are cheaper in interior markets than is green-sawn lumber from southeast Alaska (USDA Forest Service 1982). Another factor in the minimal domestic utilization of Alaska timber is the demand for products that are not produced in Alaska, such as kiln-dried lumber and softwood plywood.

Transporting Alaska Forest Products

Figure 1 shows the major trade routes used in Alaska waterborne trade. Most shipments are to foreign destinations, mostly around the Pacific Rim. The Jones Act affects both coastal shipments within Alaska and shipments between ports in Alaska and those, such as Seattle, that are separated by ocean or by an intervening nation. Intercoastal shipments of Alaska forest products to the eastern United States are also regulated by the Jones Act but are nonexistent.

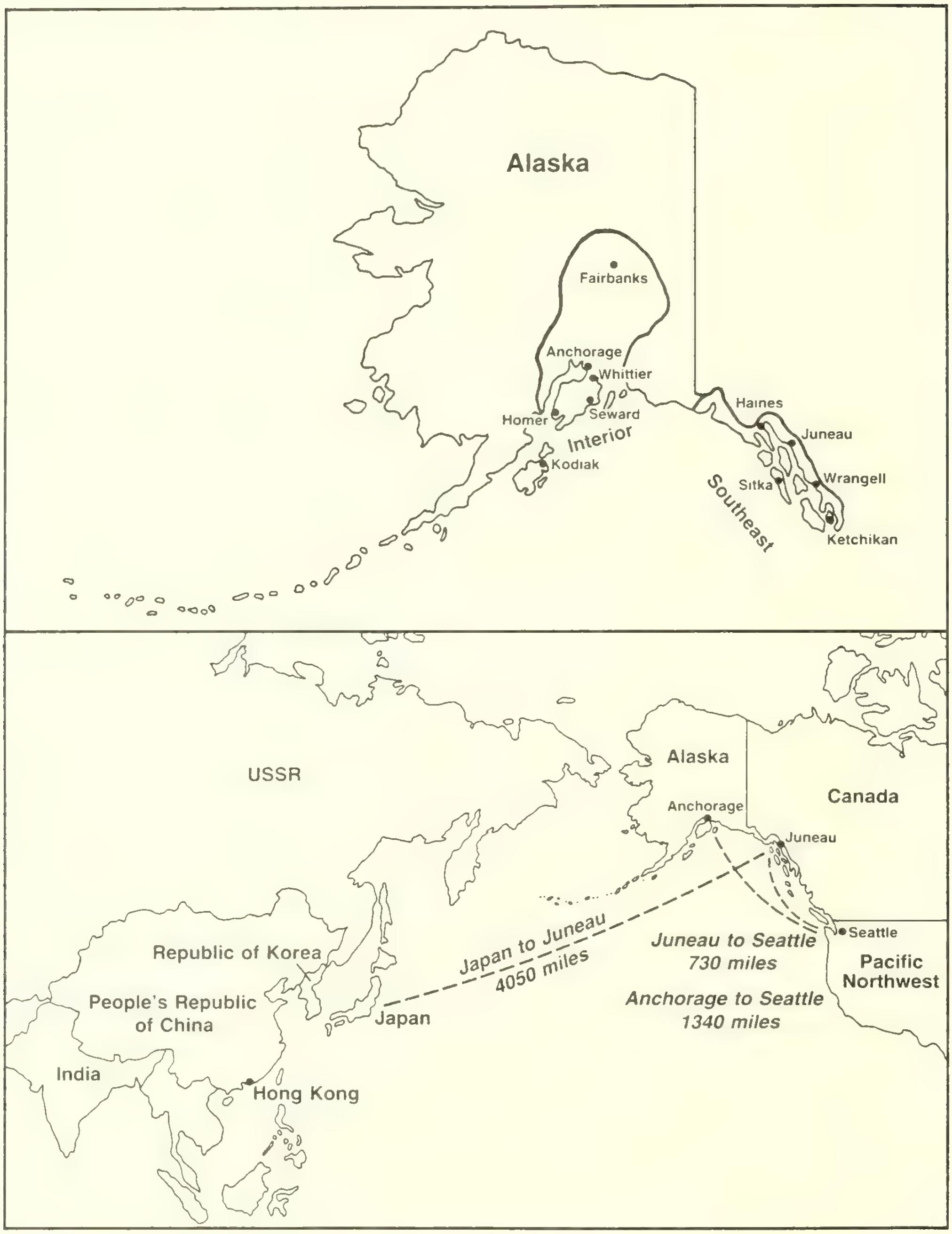

Figure 1—The interior and southeast regions of Alaska and major trading partners around the Pacific Rim.

Domestic shipments use two main types of vessels—tankers and barges—that haul mostly petroleum, dry bulk, and general cargoes. Barge shipments consist principally of consumer goods moving to Alaska, with some natural resource products carried on the backhaul to the Pacific Northwest. Ocean barging has increased in the last 30 years, mainly because barges do not require deepwater ports and can carry high-bulk, low-value commodities without time limits. Alaska barges often carry logs, pulp, and wood chips, as well as other forest products (Jackson 1983).

Most of the demand in Alaska for forest products comes from Anchorage and the populous interior region and is supplied by ocean barges from the Puget Sound area. Construction lumber, plywood, and other forest products are transported by railcar or container barge to Whittier, Seward, or Anchorage, and then by rail or truck to final destinations.

Logs harvested in southeast Alaska are towed to processing sites in log rafts or on a log barge. The mode is determined mostly by transportation cost, but route and distance also affect the decision. We estimated log barge movements to have an average 190-mile hauling distance; log rafts average 150 miles.

Appendix 1 contains the shipping information for selected Alaska forest products used throughout the study to test effects of the Jones Act. These tables in appendix 1 include route specifications, 1982 freight rates, the 1982 F.O.B. dock prices, and the volume traded for each of the major products.

Previous Analyses of the Jones Act

The Merchant Marine Act of 1920 (the Jones Act) was suggested by private shipping interests and was passed by Congress to discriminate against foreign shipping, to protect domestic interests, and to revive the declining private merchant marine (Boyd 1981). Section 27, sponsored by Senator Wesley Jones, deals with "transportation of merchandise between points in the United States" (Merchant Marine Act 1920). This states:

> . . .That no merchandise shall be transported by water, or by land and water, on penalty of forfeiture thereof, between points in the United States, including Districts, Territories, and Possessions thereof embraced within the coastwise laws, either directly or via a foreign port, or for any part of the transportation, in any other vessel than a vessel built in and documented under the laws of the United States and owned by persons who are citizens of the United States. . . .

This section extended previous cabotage restrictions by requiring the use of ships built in, crewed by, and owned by U.S. companies for all domestic trade, including that in Alaska.

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Analysis of the effects of the Jones Act has been done for certain facets of both the Alaska economy and the Pacific Northwest forest products industry. Studies have been done by Kaplan (1970), the Alaska Statehood Commission (1982), and A.R. Tussing and Associates (1982) on general transportation issues. Both I.P. Morgan (1980) and R.G. Boyd (1981) concentrated on the effects of the Jones Act on the forest products industry in the lower 48 States. Simat, Helliesen and Eichner, Inc. (1982—this will be referred to as "the Simat study") examined the effects of the Jones Act on the Alaska oil trade. Our report will be the first to focus on the combination of Alaska forest industries and the effects of the Jones Act.

No laws regulate other transportation modes like the Jones Act does waterborne shipping. Where other modes of transportation are not available, as in the Alaska waterborne trade, it is generally believed that the shipping public, the producers, and final consumers subsidize the higher transportation costs resulting from the Jones Act (Leback and McConnell 1983). Even a small difference in transportation costs can be sufficient to shift markets if no other factors interfere. The net effect of higher costs may be distortion of normal trade patterns and reorientation of the affected economies toward foreign trade where lower ocean freight rates are available (U.S. Congress, Senate 1970).

In 1970, Kaplan calculated the effects of the Jones Act on living costs. For Alaska, ocean freight charges accounted for 4.5 to 5 percent of personal expenditures. Savings from changing the Jones Act were unlikely to reduce transportation costs by more than 1.5 percent. The major finding was that demand for services and a shortage of labor distorted the cost of living in Alaska much more than transportation costs did.

In 1982, Totem Ocean Trailer Express compared consumer retail prices in Seattle and in Anchorage for the Alaska Statehood Commission (1982). This study revealed that prices averaged 8.5 percent higher in Anchorage than in Seattle. Transportation costs were only 22 percent of the average price difference and were less than 2 percent of the Anchorage retail price. However, plywood was priced 52.8 percent higher in Anchorage; transportation costs were only 18.3 percent of the Anchorage price, but were 34.7 percent of the total price difference. Food and construction materials from the Pacific Northwest appeared to be most affected by transportation costs.

Some of Alaska's present export industries are oriented to overseas markets where the Jones Act is irrelevant. Other industries can take advantage of lower cost, southbound backhaul rates (A.R. Tussing and Associates 1982). The Tussing study concludes that because few shippers now take advantage of Canadian markets or existing exemptions, the effective burden of the Jones Act on general merchandise imports to Alaska is not great. The major effect is on southbound bulk commodities and on the petroleum industry. The extent that structural development of Alaska markets was affected by the Jones Act was not testable, as no alternative evidence exists.

Morgan (1980) studied how Pacific Northwest forest products producers, excluding those in Alaska, shift their production strategies in response to shipping changes in the United States. His results indicate that providing U.S. barge operators access to foreign-built tugs and barges would have little effect on existing trades. Nor would removal of cabotage laws equalize competition with British Columbia producers for East Coast markets. Morgan concluded that the main effect of these laws is to accelerate the restructuring of the U.S. forest products industry. These adjustments, already in place, consist of supplying the Japanese export trade and moving production to the southeastern United States to supply East Coast markets.

Boyd (1981) developed a mathematical programming model to quantify the impact of the Jones Act on the U.S. lumber industry, excluding Alaska. He concluded that the present economic effect of the Jones Act on the softwood lumber industry in the lower 48 States is small and insignificant. Changing Jones Act restrictions did lead, however, to changes in lumber prices and trade flows.

The Simat study (1982) used a cost-determined freight rate approach to determine the effect of the Jones Act on petroleum shipments. It estimated shipping costs to Alaska and Jones Act premiums by vessel type by comparing the component costs of actual service with equivalent foreign-flag costs for similar vessels. Using a simulation model of vessel and service characteristics and basic cost data, vessel route costs were converted to a cost-per-unit freight rate. This served as the minimum rate that must be earned to sustain service on that route (Simat study 1982).

The Simat study concluded that Alaska is served by a competitive liner transport system with low rates already available. Because most costs in modern container operations are not flag related, the possible reductions from changes in the Jones Act are low. Bulk carriers in the southbound trades are mostly charter vessels. Changes in U.S. regulations would not greatly affect this mode, as long-term charters will continue to control these freight rates. The Simat study found that the oil tanker trade would show the greatest response to lifting of Jones Act restrictions, as an excess supply of tankers exists on the world market. The Simat study is the most comprehensive study of Jones Act effects on the Alaska economy, but does not specifically address effects on forest products.

Applicability of the results of these studies on the Jones Act to our study is somewhat limited. Most other studies analyze complete removal of the Jones Act; that is, allowing foreign-flag vessels into the domestic trade. We only allowed entry of U.S.-flag, foreign-built vessels in testing the first objective of this study. A limited change in the Jones Act is perceived to be more feasible than a total change because of potential reactions by special interest groups. If Alaska continues to rely on barge traffic, foreign-built barges could enter this U.S.-flag trade; thus, Alaska barge traffic could retain a competitive advantage over other flags and shipping modes.

Calculating the Effects of the Jones Act

To assess the effects of the Jones Act on the Alaska forest products trade, we constructed a partial equilibrium model of 1982 trade patterns. Using resource rent theory and a linear program to simulate product shipments, we estimated the direct effects of the Jones Act in Alaska. Details of this process are presented by Jackson (1984).

Meeting the Objectives

The three objectives of this study are related. The data collected for the first objective were used to determine the existence and scope of Jones Act differentials. This data set was also used in the partial equilibrium model to estimate the effects of Jones Act freight rates on the direction of trade (the second objective). These results were then used to estimate the effects on net returns and on consumption. This met the third objective: to measure the monetary losses incurred by producers and consumers in Alaska. Positive responses in all three steps rejected our null hypothesis that the Jones Act would have no economic effects on Alaska forest products trade.

The existence of a U.S.-flag rate differential (objective 1) could be confirmed by comparing quoted rates on the same products and routes where equivalent U.S.- and foreign-flag vessels operate. This was possible for only a few, mostly foreign, routes. Only U.S.-flag vessels are now permitted to operate on routes restricted by the Jones Act, and their numbers are few. There is some comparability with ocean rates on long coastwise and intercoastal routes; however, direct comparison was not possible as rate information was not disclosed.

To meet objective 1, we applied the technique used in the Simat study (1982) to the specific Alaska trades involved in our analysis. After collecting 1982 transportation data, we calibrated it with the Simat rates. This calibrated data set was used to calculate the Jones Act freight rate differentials for all applicable routes (Cathcart 1984).

The second objective addressed the effects of the Jones Act on the direction of trade. Our partial equilibrium model of Alaska forest products movements is detailed in appendix 2. This model was run twice using two data sets; the Jones Act freight rates and the unrestricted freight rates. The first run was calibrated to existing 1982 trade patterns and used transportation costs incurred under the Jones Act. The second run tested the effects of an immediate change to transportation rates that were unaffected by Jones Act restrictions on place of construction.

For objective 3, estimates of the primary impacts on each trade route were found by identifying the rate differential between Jones Act trade and unrestricted trade. The model of objective 2 also solved for changes in markets for individual products. Each affected trade volume was multiplied by the change in the freight rate to compute gains under unrestricted trade. The increases in revenue for the internal barge and raft movements and the cost reductions for forest products moving into Alaska also were added. This gave the total primary impact of the Jones Act on the Alaska timber economy, thus satisfying objective 3.

The Theory of Resource Rent

Waterborne transportation of Alaska forest products to foreign and domestic markets is the last in a series of processing steps. Each step consists of intermediate inputs of resources, manufacturing, marketing, and transportation services.

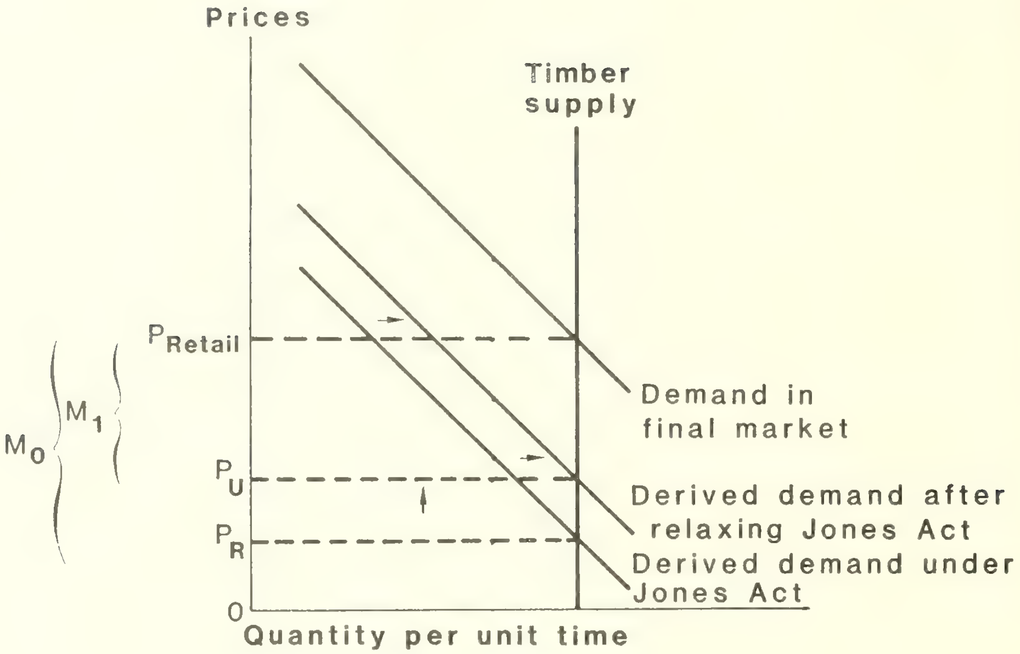
The level of consumption in the final market is a function of product demand and supply. This product demand is a joint demand for all inputs used in the final goods. Likewise, the price-quantity inputs at intermediate production points form the basis for derived demand functions (Tomek and Robinson 1972). These are derived by subtracting the costs of marketing and production (the marketing margin) from demand at each processing step. The demand for a factor of production, such as stumpage, is derived in this way.

Rents on these factors can be measured at a number of levels of the production process: as land value, as stumpage value, or as F.O.B. dock prices. Stumpage value—the difference between the selling price of the exported forest product and the entire industrial stump-to-market cost, including an allowance for profit and risk—is defined as a resource rent (Davis 1966).

The marketing margin between final markets and the last processing step in Alaska is dominated by waterborne transportation costs; the internal transfers between the woods and mills are dominated by those same costs. The Jones Act affects only internal barging and rafting costs for transportation to foreign destinations. Relaxing the Jones Act constraint for shipping to U.S. destinations should decrease shipping costs, thus decreasing both the final marketing and internal transfer margins.

Waterborne transportation costs can be capitalized out of resource values as part of a fixed marketing margin. A decrease in the margin changes F.O.B. prices by the same amount as the stumpage price changes. Thus, F.O.B. changes may be used in the analysis.

When a change in the cost of providing existing services occurs, both retail and producer prices may change. This change in the margin appears as a shift in the derived demand and derived supply functions for the product. The magnitude of the price change at each level depends on the slopes of the supply and demand curves. In the extreme, if the primary supply curve is vertical (figure 2), the entire amount of the margin change ($M_1 - M_0$) will accrue to the producers. A decrease in the margin results in an increase in the producer price and a narrower margin.



P_R –Price restricted by effects of the Jones Act

P_U –Price unrestricted by effects of the Jones Act

M_0 –High transportation cost marketing margin

M_1 –Low transportation cost marketing margin

Figure 2—Distribution of the gains from a change in the marketing margin.

Assumptions

The basic assumptions necessary to use a partial equilibrium model of the Alaska forest products trade can be grouped into timber supply, transportation supply, and competitive market categories.

All institutional factors, except transportation, that affect timber supply were held constant. These factors included two 50-year timber sales, primary manufacturing regulations on public ownerships, and transportation infrastructure, such as harbors, wharves, and landings. The resource rent model we employed assumed that the supply function of all inputs was fixed at a given level (Friedman 1962). Costs were assumed to be equivalent for all firms. F.O.B. dock prices for any single product were assumed to reflect constant harvesting, primary processing, marketing, energy, and prior transport costs. All price fluctuations were held constant and assumed to have occurred outside the 1982 analysis period.

We assumed that timber harvests would be no less than 1982 recorded levels. This was supported by poor market conditions and by indications that the southeast Alaska timber economy was close to shutting down. Total timber supply was assumed to be greater than total shipments on all routes. Because Alaska is a small-volume supplier, total price responsiveness exists in the roundwood supply curve in the short term.

The long-run Alaska timber supply curve equals regional timber capacity (Rideout 1984). This is compatible with the theory and behavior of market-run timber supply curves (Gregory 1972). Inventories were held constant to constrain producers to supply at or above the 1982 level.

The fixed-input proportion assumption means transportation services and shipping capacity, by route, were held proportional to the volume traded. Economies of scale in the shipping industry were acknowledged, but were held constant at 1982 levels. Container movements in the Jones Act trade represented movements on existing vessel types—smaller bulk carriers, container ships, and tug-barge systems. The probable entry of larger vessels or the possible use of advanced technology in coastwise trade was not included because of data limitations.

The supply of shipping services was assumed to be sufficient to satisfy demand. If increased service was required owing to changing restrictions, the same types of foreign-built, U.S.-flag vessels were allowed entry. Retention of the ownership, manning, insurance, and repair constraints implies that existing shipping firms will reduce costs by purchasing foreign hulls but that the actual firms involved may not change. Repair services are already located in Pacific Northwest and Alaska ports and are not expected to shift to foreign ownership.

Assuming perfect competition in the Alaska forest products marketplace requires that certain conditions hold. Changing the price structure facing Alaska timber producers could alter equilibrium behavior, however. Perfect knowledge of flows and prices may be as unavailable to all participants as it was to us. Free entry and exit of business firms was difficult to superimpose on an industry dominated by two long-term timber sale contracts. In the actual Alaska shipping and forest products industries, margins may not be perfectly constant; however, most Alaska forest products are a small part of world markets. We therefore considered these conditions sufficiently constant for testing our Jones Act hypotheses.

The above assumptions, combined with resource rent theory, allowed the complete transfer of changes in the transportation costs to F.O.B. product prices. These prices served as a proxy for an increase in stumpage prices in tests of relaxing the Jones Act. The entire amount of a reduction in Jones Act freight rates thus caused a corresponding increase in the resource rent of Alaska stumpage.

Data Collection and Freight Rate Estimation

A preliminary review of Alaska's forest products trade indicated that timber production, processing, trade, and price information were required. Several sources for this information were used. The Alaska forest industries and Native Corporations provided most of the information. Federal agencies and port authorities provided most of the trade statistics. Private shipping interests and forest industries in the Pacific Northwest and British Columbia were reluctant to participate, although they did provide some freight rates.

Information on freight rates and product prices was difficult to obtain. Most firms quoted confidentiality as the barrier to sharing this information. Another limiting factor was the state of the economy in southeast Alaska. Several firms were either not operating in 1982 or were producing at levels below normal. This meant that several routes were inactive and that less data were available. Some information was available on major modes and stowage factors. Table 2 contains information on shipments of the main Alaska products, vessel capacity, stowage factors, and sample 1982 costs per unit of cargo. To prevent individual disclosures, we aggregated values into representative product groups and used an average of the sometimes wide-ranging values.

Because much information was missing or incomplete, we used four data sources as limited substitutes for actual market data. Forest product prices, volume flows, and aggregate demand were extracted from the U.S. Department of Commerce (1982), Statistics Canada (1982), Ruderman (1982), and the U.S. Army, Corps of Engineers (1982), data bases. Our final set of costs and prices was sent back to the sources for review during December 1983. Their responses helped identify and repair any inconsistencies in the data.

Most harvested timber moves by water at least once before processing or export. Each of the products under analysis—logs, pulpwood, lumber, pulp, and chips—requires different transportation services. Also, the vessels used vary between routes to the lower 48 States and routes to foreign destinations. Information on each product-route-vessel combination was collected for the model and is presented in appendix 1. Sample 1982 F.O.B. rent estimates are included with this trade flow data. We also collected data on transportation costs from the woods to the mill (or the deepwater landing site) to calculate the barging and rafting costs for internal southeast Alaska movements.

Table 2—Vessel dead weight tonnage, stowage factors, and cost per unit cargo for the major vessel types used in the Alaska forest products trade, 1982

Type of vessel	Products	Vessel dead weight tonnage	Stowage factor	Cost per unit cargo
Log carrier	Logs	16,000-30,000	2.8-5.2 MMBF	$90/MBF
Break-bulk	Lumber/cants	16,000-18,000	6-9 MMBF	$70/MBF
Container	Lumber/cants	16,000-18,000	13-15 MBF/40 ft	1,500/40 ft
Chip carrier	Wood chips	20,000-50,000	15,000-39,000 MT	$48/MT
Pulp carrier	Pulp bales	13,500 avg.	11,500 MT avg.	$66/MT
Container	Pulp bales	15,600 avg.	13,000 MT avg.	$75/MT

The largest cost penalties imposed by the Jones Act occur in capital costs, insurance, labor, fuel, repairs, and maintenance. Figure 3 shows cost differences for U.S.- and foreign-flag vessels in the tug and barge and the bulk carrier trades. The Simat study (1982) methodology uses cost data for U.S.- and foreign-flag vessels to calibrate freight rates on eight services. After we collected 1982 freight rates on three of these services, Cathcart (1984) calibrated costs for both U.S.- and foreign-flag vessels with the Simat rates. We used a Seattle-to-Anchorage container ship service to model the movement of consumer items and building products. A tug and barge service operating between Seattle and Whittier also represented the transport of building materials and general cargo from the the lower 48 States. Shipment of logs to the lower 48 States was modeled using bulk carrier service from Ketchikan to Seattle.

The rate differentials that we used to calculate changes in freight rates on each route are listed in table 3. These are lower than the differentials by country of registry as estimated for international grain trade. They are consistent, however, with estimates from other sources for the Alaska forest products trade, which ranged from 13 to 43 percent with the most frequent being 30 percent.

The Simat study (1982) cost differentials for each forest product trade route were applied to our 1982 freight rates to determine the changes that would result from relaxing the Jones Act. Each change was also added to the resource rent to transfer the change to the timber producers. Any gains in resource rents due to altering the Jones Act eventually showed as increased stumpage prices, given constant selling prices at the delivery point.

The Partial Equilibrium Model

The partial equilibrium model used in this analysis of the Jones Act maximizes rent in the standard linear programming format (Dorfman 1958). A description of the model is provided in appendix 2. Rent maximization, rather than transportation cost minimization, was chosen for several reasons. Direction of trade is a function of delivered price as well as of transport cost. F.O.B. product prices can be used as a proxy for stumpage prices in a rent maximization model. Financial implications for the Alaska economy also may be directly aggregated and interpreted using resource rents.

The model maximized Alaska resource rents that resulted from Pacific Rim trade. The supply and demand regions used in the model are listed in appendix 2. Supply and demand constraints placed some restrictions on rent optimization, including requiring all volume flows to be nonnegative. Shipments from each supplier could not exceed the 1982 capacity of that supplier. The total supplied from all producers had to be less than the total capacity of all producers. The last constraint was that total shipments to each demand region had to equal the quantity consumed in that region. Regional consumptions in 1982 were inflated by 10 percent, under constant 1982 prices, to allow the model to reach new equilibria. Capacity constraints in the model effectively bounded supply between low-level movements in 1982 and the regional capacity of southeast Alaska.

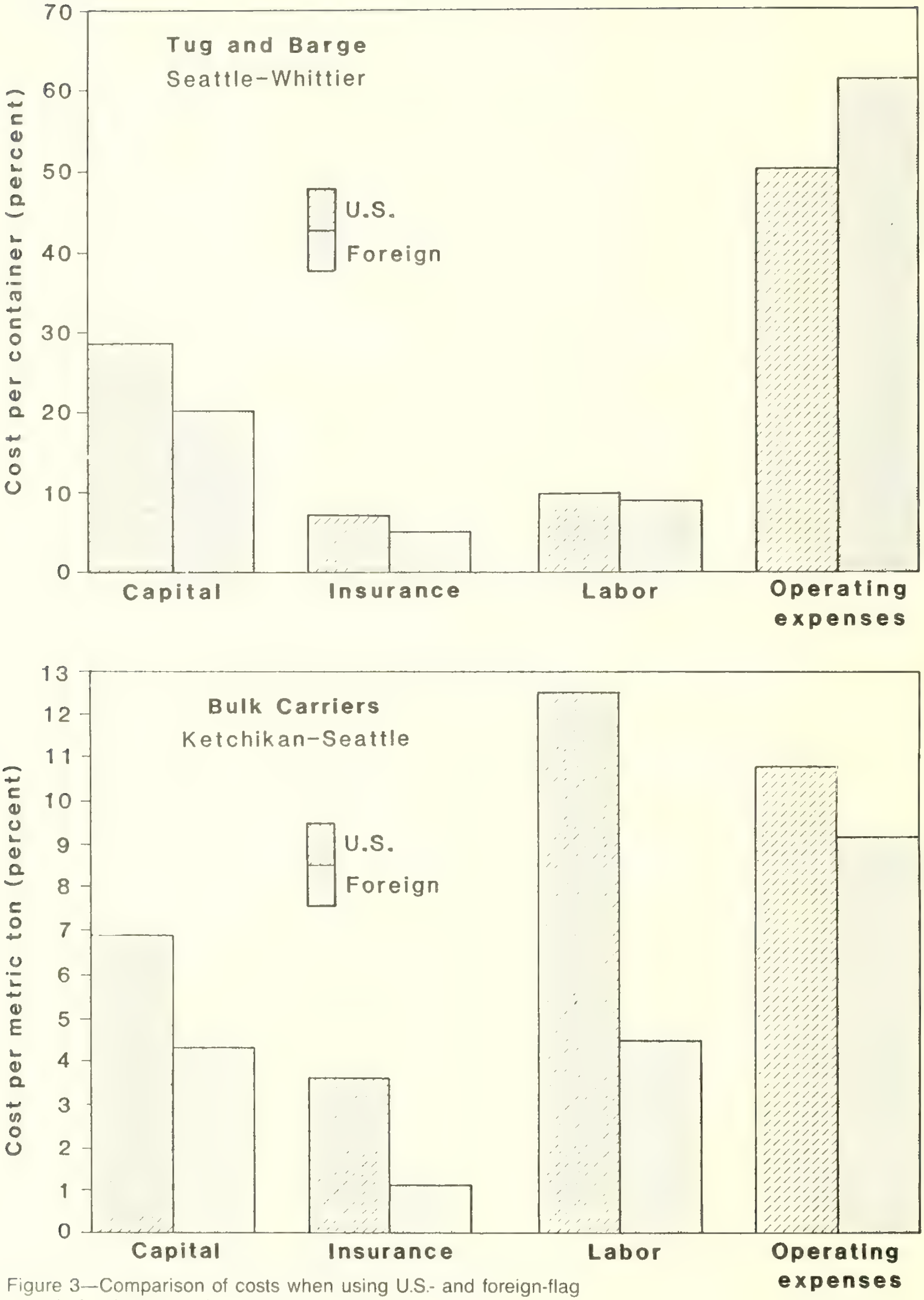


Figure 3—Comparison of costs when using U.S.- and foreign-flag vessels for the tug and barge and bulk carrier trades.

Table 3—1982 trade routes, Jones Act freight rates, rate differentials, and changes in Jones Act freight rates for logs, pulpwood, lumber, wood chips, and wood pulp, by shipping mode, in the domestic timber trade in Alaska, as a result of relaxing the Jones Act

Shipping mode	Trade route	Jones Act freight rate	Rate differential	Change in freight rate
		$/unit	percent	$/unit
		LOGS (MBF)		
Tug and barge	SE-PNW	64.00	19.0	12.16
Tug and barge	SE-INT	52.80	19.0	10.03
Tug and log barge	SE-SE	45.08	26.6	11.99
Tug and raft	SE-SE	17.70	6.4	1.14
		PULPWOOD (MBF)		
Tug and barge	SE-PNW	72.13	19.0	13.70
Tug and log barge	SE-SE	50.81	26.6	13.52
Tug and raft	SE-SE	19.95	6.4	1.27
		LUMBER (MBF)		
Tug and barge	SE-PNW	27.00	19.0	5.13
Tug and barge	SE-SE	7.26	19.0	1.38
Tug and barge	SE-INT	29.04	19.0	5.52
Tug and barge	PNW-SE	32.00	19.0	6.08
Tug and barge	PNW-INT	72.00	19.0	13.68
Container ship	SE-PNW	43.38	13.4	5.81
Container ship	PNW-INT	95.00	13.4	12.73
		WOOD CHIPS (MT)		
Tug and barge	SE-PNW	19.46	19.0	3.71
Tug and barge	PNW-SE	19.46	19.0	3.71
Tug and chip barge	SE-SE	12.00	13.1	1.57
		WOOD PULP (MT)		
Tug and barge	SE-PNW	19.00	19.0	3.61

SE = southeast Alaska; INT = interior Alaska; PNW = Pacific Northwest.

Sources: Simat, Helliesen and Eichner, Inc., 1982; Cathcart 1984.

Domestic routes were defined in two ways. The actual volume of trade defined the majority of routes between the British Columbia supply region and the Alaska and Pacific Northwest demand regions. Forest products trade between Alaska and the Pacific Northwest was minimal. The only viable routes were northbound shipments of lumber and building products and southbound shipments of pulp. Consequently, potential routes had to be created to test altering of the Jones Act. Local movements in Alaska were treated in the calculations for internal barging and rafting.

The major Alaska ports involved in forest products shipments are Ketchikan, Wrangell, Sitka, Metlakatla, Haines, Kodiak, and the ports supplying interior Alaska. The first five are active, individual timber export facilities, but were grouped as a single supply region, southeast Alaska, in the model. Kodiak is also an export port serving south-central Alaska. The major ports serving interior Alaska are Anchorage, Whittier, Seward, and Palmer where waterborne shipments of building supplies are transferred to either truck or rail service for land transport.

Internal Barging and Rafting Calculations

Primary movements, including log and chip transfers, within southeast Alaska and to the interior were originally included in the data matrix. This resulted in the model double-counting volumes and in biased results. To correct this problem, local barging and rafting calculations were separated from the main model. Barging and rafting are the only transportation choices for Alaska roundwood, as even most export logs move by water to deepwater landings. These movements are subject to Jones Act regulation. Changing the Jones Act will directly affect resource rents at stumpage price levels in addition to other changes measured in F.O.B. values after processing.

We assumed that 1982 represented the lower limit of roundwood flows for Alaska and that volumes barged and rafted were constant for the 1982 period of analysis. Changes in the cost per mile of barging and of rafting services may actually result in quantity transfers between the two modes. The barging and rafting calculations are described in Cathcart (1984).

The same rate estimation techniques were applied in the main model and in the barging and rafting calculations. This was consistent with our assumption that trade within southeast Alaska would retain the comparative advantages of U.S. ownership and labor without the Jones Act restrictions on construction.

No volume shifts were permitted in the barging and rafting calculations because of data limitations. The change in rent was calculated as the change in the freight rate multiplied by the volume moved on that route. In reality, lower transport costs on internal Alaska routes could shift roundwood to different end products. As further research provides better information, this model could be expanded to better represent changes in volume flows and product shifts.

The routes representing interior and southeast Alaska lumber sales were retained in the main model. These local movements occur on commercial barge services and are final transportation movements. Pulpwood movements in southeast Alaska are retained in the main model and also in calculations of the internal movements. These two entries were considered distinct because movements in the main model represented a supply of pulpwood currently unused on Native Corporation lands. The hypothesis was that a shift in rents could make use of pulpwood profitable as Native harvests are exempt from export restrictions. Including pulpwood in the main model allowed for movements out of Alaska; the internal movements described transfers to processing sites within the State.

Indirect and Induced Effects

Our estimation of impacts from the Jones Act were limited to direct effects only. Changes in wealth were assumed to return to timber growers and forest products consumers to the detriment of the domestic shipping industry. Although the Alaska economy is small and very dependent on imports and exports, a complex set of economic interactions between industrial sectors still exists. Changes in the Jones Act that would benefit the forest products sector would indirectly impact other sectors in addition to marine transportation, forest products, and construction.

Input-output (I/O) models are one tool that can be used to trace an economy's transactions and how changes affect each sector. We estimated the secondary effects of relaxing the Jones Act within the Alaska economy in 1982 by using the Alaska input-output model (IPASS) as developed by the USDA Forest Service (Olson and others 1984). The IPASS model forecasts selected economic indicators over time from initial I/O relationships. Our results were used to adjust the IPASS transportation cost coefficients for forest products movements to simulate the effects on Alaska gross outputs and services.

All economic change takes time, and a change in the Jones Act in one sector would dynamically affect investment rates, subsequent final demands, and employment elsewhere. We used a set of alternative IPASS scenarios to measure the combined direct, indirect, and induced impacts. Our baseline scenario presumed no changes in the Jones Act. The impact scenario assumed that our estimated Jones Act effects began in 1982. Both scenarios were forecast to 1987 for comparison. In both cases, we assumed that the 1977 economic relationships that define the I/O matrix were also representative, in real terms, of our 1982 starting point.

Impacts of the Jones Act

Impacts of the Jones Act on the Alaska forest products industry were measured in several areas. To satisfy the first objective of this study, the effects on freight rates were measured to establish baseline rates. Shifts in the direction of trade were estimated for the first objective, as were the impacts on rents on both coastwise and internal routes. The penalties placed on imports of forest products from the Pacific Northwest were also estimated. Finally, the effects on the Alaska economy as a whole were estimated to show the total impact of the Jones Act and to meet all three objectives.

Freight Rate Differentials

A Jones Act-induced freight rate differential does exist for all domestic waterborne carriers in the Alaska forest products trade. Calculated values of these differentials for the vessels used in each trade are reported in table 3. The magnitude of the freight rate differential (the change in the margin) was interpreted as an increase in the resource rent for timber producers.

The greatest gain after relaxing the Jones Act was on the local southeast Alaska tug and log barge route. A 26.6-percent reduction in the freight rate indicated that significant savings can be realized once existing U.S.-built tugs and barges are replaced by foreign-built vessels. Resource rents increased by $11.99/MBF (thousand board feet) for saw logs and $13.52/MBF for pulpwood, on average routes, after relaxing the Jones Act in 1982. With access to lower tug capital costs, rafting of logs showed a 6.4-percent decrease in the freight rates. This would increase resource rents for rafting saw logs by $1.14/MBF and for rafting pulpwood by $1.27/MBF.

The large savings indicated in the tug and barge mode were limited by the differences between the costs for rafting logs and for barging logs (table 2) within southeast Alaska and by the cost-minimizing actions of the timber producers. Regardless of the size of the rate reduction, barging will substitute for rafting only when the total transportation cost is less.

Shippers using commercial barge services in the Seattle-Alaska lumber trade would realize an overall savings of 19 percent if foreign-built vessels were allowed in the trade. This results in a savings of $6.08/MBF for northbound cargo and $5.13/MBF for lumber moving from southeast Alaska to the Pacific Northwest. The difference between these two rates is due to the backhaul effect.

Container ships are the current alternative to tugs and barges in the coastwise lumber trade. They could be 13.4 percent cheaper if the Jones Act constraint were relaxed. Again, comparison of total freight rates, and not just changes in the margin, indicated that few modal shifts would occur. Container ship rates are higher and are unlikely to drop enough to truly compete with barging systems. No tramp bulk trade exists between the Pacific Northwest and Alaska, but elsewhere, rates are comparable to barging. If foreign-built bulk vessels are allowed on the southeast Alaska-Pacific Northwest route, forest products savings would be similar to savings under barging where suitable ports exist.

Direction of Trade

A reduction in the freight rate created a cost savings that translated to higher resource rents for Alaska timber producers and lower costs to Alaska consumers. The savings were too small, however, to change trade flow patterns in Alaska markets. The most notable result was that little trade shifted by quantity, by destination, or by mode of carriage. After relaxing the Jones Act, Alaska resource rents showed only small changes in the domestic flow of Alaska forest products. These changes are summarized in table 4.

Table 4—Shifts in quantities traded, transportation mode, and final destination of southeast Alaska forest products due to changes in freight rates caused by relaxing the Jones Act

Product	Final destination	Transportation mode	Reduction in freight rate	Change in quantity traded
			$/MBF	MBF
Spruce cants	Pacific NW	Tug and barge	5.13	-2,918
Spruce cants	Pacific NW	Container ship 1/	5.81	2,918
Hemlock cants	Pacific NW	Tug and barge	5.13	-4,968
Hemlock cants	Pacific NW	Container ship 1/	5.81	4,968
Pulpwood	SE Alaska	Tug and raft	1.27	-69,150
Pulpwood	Pacific NW	Tug and barge	13.70	69,150

NW = northwest; SE = southeast.

1/ Shift from tug and barge to container ship based solely on the change in F.O.B. values. Modal selection based on total cost will favor the tug and barge mode at 1982 freight rates.

Initial inspection of foreign and domestic product prices (appendix 1) suggested that existing market price differentials could exceed any penalties imposed by the Jones Act on domestic trade routes. Model simulation proved this to be the case. The direct effect of the Jones Act was limited to movements along existing domestic routes and to internal movements of barged and rafted logs. Sensitivity analysis revealed that the price differential necessary to shift trade was too great for most products. With two exceptions, trade was unaffected even though freight rates decreased on all existing and potential coastwise routes.

The first shift in trade flows was a small-volume switch from barge service to container ships in the spruce and hemlock cant trade from southeast Alaska to the Pacific Northwest. The higher freight rate for container ships caused a larger change in the margin, although the percentage of change was less. This incorrectly raised the resource rent for that trade route. Given unequal freight rates on the same route, volume will actually shift into the mode with the lowest freight rate, not the one with the largest change in the margin. When the relative freight rates were analyzed, with and without the Jones Act, barge traffic was still the preferred mode for the same product.

Insufficient trade on the route from southeast Alaska to the Pacific Northwest occurred in 1982 on break-bulk vessels for any data to be included in the model. Foreign-built vessels would have a comparative advantage here, and this route may be long enough for them to exercise that advantage over barges. Bulk cargo freight rates could decrease as much as 21 percent if the Jones Act were relaxed. Break-bulk freight rates were between barge rates and container ship rates in magnitude. Other factors, such as the necessity for multiple-site loading, still weigh against coastwise break-bulk movements. Because changing barge and container ship freight rates did not change the level of volume traded, using break-bulk carriers should not either. As modal shifts occurred between barges and container ships, it was more likely that changes in break-bulk rates would affect modal choices.

The second, significant trade flow shift was a change in destination for southeast Alaska pulpwood logs. The greater change in the tug and barge resource rent (+$13.70/MBF) for the Pacific Northwest route over the internal (+$13.52/MBF) route was partially due to the longer distance involved. Within southeast Alaska, Native Corporation pulpwood shifted from internal rafting to southbound barge movement (table 3). We interpreted this shift as increased production from Native lands because utility volume is currently left in the woods, because British Columbia sources are increasing their southeast Alaska market shares, and because Native Corporations may legally export unprocessed roundwood.

This shift in pulpwood movements was significant, as it was the only change in a trade route that resulted from relaxing the Jones Act. This should not be viewed as sufficient evidence for initiating profitable trade on this route. Our analysis used generalized, representative data and was not designed to give precise estimates of feasibility.

Rents for Alaska Forest Products

The primary impacts of a cost differential on the resource rents accruing to Alaska forest products were relatively small in the coastwise trade. The total estimated rent of the Alaska forest products trade was $504,015,880 under the Jones Act. Without the Jones Act constraint, this increased to $505,417,017. The difference, $1,401,137, was the total calculated change in the margin. After correcting for errors in modal choice, resource rents increased by $1,355,319 as a result of relaxing the Jones Act on these routes. This represented an impact of 0.3 percent on the total wholesale (F.O.B.) value of Alaska forest products exports to all destinations and 6.5 percent of the value of existing exports to the Pacific Northwest.

The internal shipments of southeast Alaska forest products are pulpwood and saw logs moving by raft or log barge, and wood chips moving on chip barges. If the Jones Act were relaxed, the entire change in resource rent would result from changes in freight rates. Because volumes moving on given routes were assumed to remain constant, the change in rent was simply the change in the dollar-per-unit freight rate multiplied by the volume moved. Residual rents for pulpwood increased by $320,676; by $373,255 for saw logs; and by $328,951 for wood chips (table 4). The requirement that all forest products moved within Alaska be on Jones Act vessels increased freight rates by $1,022,881 in 1982. Under improved market conditions, this impact would increase as more volume leaves the woods and is transported to processing sites.

The effect of the Jones Act on 1982 Alaska resource rents of primary products was almost as great as the effect on coastwise trade. The rate differential was less owing to shorter routes, but the penalty was greater because all logs and chips moved from the forest to the primary processing site by water. A double penalty under the Jones Act also exists for final products exported to the lower 48 States, but because most Alaska wood exports were transported to foreign markets in 1982, the impact was small.

If the Jones Act constraint were relaxed, the relative advantage of log barging would be improved. Although barge rates would still be higher than those for rafting, the use of more barge routes could become economically feasible. Lower freight rates would also extend the distances that would be economical for towing and barging and increase the feasibility of gaining access to more remote supply areas.

Effects on calculated internal movements added $1,022,881 to the $1,355,319 coastwise savings in trade costs; the total resource rents after relaxing the Jones Act increased to $2,378,200 for the 1982 analysis period. Although measured by F.O.B. values, the difference in resource rents accrued to, and was realized by, stumpage owners, including the Forest Service, Native Corporations, and the State of Alaska. Table 5 reports the estimated increases in resource rent accruing to each Alaska forest product export on all modes as a result of relaxing the Jones Act.

Imported Forest Products

The effect of relaxing the Jones Act on movements of imported forest products is much simpler. Assuming a fixed demand for finished wood and construction materials allowed the volumes shipped and consumed to be held constant. The tug and barge cost savings of 19 percent translated into a $6.08/MBF price reduction for lumber on the shorter and lower volume (34,565 MBF) Pacific Northwest to southeast Alaska route and $13.68/MBF reduction on the Pacific Northwest-interior route (159,149 MBF). Neither change was more than 3 percent of the delivered price.

The impact of the Jones Act on Alaska imports was calculated by multiplying each change in the margin by the respective volume of trade. The total effect in 1982 on forest products imported into Alaska was $2,387,313 (table 5). If shipping responds competitively and our assumptions hold, this savings could accrue to the Alaska consumer.

The Total Impact

The total 1982 Jones Act impact on forest products trade, as summarized in table 5, was $4.77 million. Half of the annual effect was borne by Alaska timber growers ($2.38 million) and half by Alaska consumers of forest products that were imported from the lower 48 States ($2.39 million).

The significance of results generated by this type of analysis may be misleading. The estimate is reliable only to three significant figures. Given the nature of the data base, no confidence intervals can be calculated.

Table 5—Changes in resource rent, by product, mode, and trade route, after relaxing the Jones Act, 1982

Product	Units	Final destination 1/	Transportation mode	Volume moved	Change freight rate	Total resource rent
				unit	$/unit	1982 dollars
			PULP			
Dissolving pulp	MT	Pacific NW	Tug and barge	24,177	3.61	87,279
Sulphite pulp	MT	Pacific NW	Tug and barge	5,427	3.61	19,591
Total pulp						106,870
			WOOD CHIPS			
Wood chips	MT	Pacific NW	Tug and barge	73,487	3.71	272,637
Wood chips	MT	SE Alaska	Tug and barge	209,523	1.57	328,951
Total wood chips						601,588
		LUMBER AND CANTS SHIPPED FROM SOUTHEAST ALASKA				
Spruce dimension	MBF	Interior	Tug and barge	88	5.52	486
Spruce dimension	MBF	SE Alaska	Tug and barge	157	1.38	217
Spruce cants	MBF	SE Alaska	Tug and barge	4,940	1.38	6,817
Hemlock dimension	MBF	SE Alaska	Tug and barge	494	1.38	682
Hemlock cants	MBF	SE Alaska	Tug and barge	8,185	1.38	11,295
Total lumber shipments						19,497
		LUMBER AND CANTS SHIPPED FROM PACIFIC NORTHWEST				
All species dimension	MBF	Interior	Tug and barge	159,149	13.68	2,177,158
All species dimension	MBF	SE Alaska	Tug and barge	34,565	6.08	210,155
Total lumber receipts						2,387,313
Total lumber trade						2,406,810
			LOGS			
Saw logs	MBF	SE Alaska	Log barge	9,980	11.99	119,657
Saw logs	MBF	SE Alaska	Tug and raft	222,454	1.14	253,598
Spruce No. 3	MBF	Interior	Tug and barge	132	10.03	1,324
Spruce No. 1	MBF	Pacific NW	Tug and barge	570	12.16	6,931
Hemlock No. 2	MBF	Pacific NW	Tug and barge	58	12.16	705
Total logs						382,215
			PULPWOOD			
Pulpwood	MBF	SE Alaska	Log barge	14,522	13.52	196,340
Pulpwood	MBF	SE Alaska	Tug and raft	97,902	13.52	124,336
Pulpwood	MBF	Pacific NW	Tug and barge	69,150	13.70	947,355
Total pulpwood						1,268,031
Total change in resource rent						4,765,514

NW = northwest; SE = southeast.

1/ All movements originate in southeast Alaska unless otherwise indicated.

The Alaska Economy

The IPASS I/O model indicates that changes in the forest products industry after relaxing the Jones Act are minimal when taken in the perspective of the entire Alaska economy. Stumpage gains are mostly transferred to the U.S. treasury, minus payments to local governments. The gains for wood consumers in Alaska are such a small proportion of total expenditures in the construction sector that the effect is not measurable.

Table 6 shows forecasts of total Alaska employment and gross output over 5 years. Redistribution of employment and gross output after relaxing the Jones Act was predictably concentrated in a few sectors. By 1987, the loss of 9 jobs in water transportation was offset by gains of 134 jobs in logging, 9 in new construction, 27 in wholesale and retail sales, and 27 in Federal, State and local government positions. The $1.7 million 1987 gross output reduction (in 1982 dollars) for the water transport sector was compensated by gains in numerous other sectors: logging increased $10 million, forestry $2.8 million, new construction $1.4 million, and wholesale and retail sales $1 million. These gains were small when dispersed over the entire Alaska economy; about 0.10 percent per year in employment and 0.09 percent per year in gross output. Most of these gains were attributed to the increased pulpwood activity.

Transportation policy changes applied to a single Alaska product had measurable, but small, impacts on the State's economy as a whole. Changing the Jones Act constraint across all sectors was beyond the scope of this study; however, such results should be significant in this geographically isolated, maritime economy.

Table 6—Direct, indirect, and induced effects on total employment and gross output from relaxing the Jones Act for the Alaska forest products trade, 1982-87

	Employment			Gross output		
Year	Jones Act	Non-Jones Act	Total gain	Jones Act	Non-Jones Act	Total gain
	1000 people years			Million 1982 dollars		
1982	193.7	193.7	NA	16,248	16,248	NA
1983	192.2	192.3	+0.1	18,173	18,185	+12
1984	200.6	200.7	+ .1	19,497	19,519	+22
1985	209.4	209.6	+ .2	20,748	20,765	+17
1986	218.8	219.0	+ .2	21,992	22,009	+17
1987	229.3	229.5	+ .2	23,359	23,387	+28
Total gains			+ .8			+96

NA = not applicable.

Qualifying the Analysis

We used sensitivity analysis to calculate the highest market prices for each product. This highlighted which changes in resource rents were necessary to further change the results. These values are listed in table 7 for those products that changed either in mode or volume level.

The shadow price indicated the marginal value of adding one more unit of volume to a route. In this model, it was also the difference between the non-Jones Act resource rent and the highest market price, usually in export markets. The shadow price indicated that several products needed a change of over $100.00 per unit to shift volume from foreign markets to the domestic trade. For example, dissolving pulp moving from southeast Alaska to the Pacific Northwest by tug and barge required a price increase of $141.39 before more dissolving pulp would shift to that route. If the resource rent rose to the highest market price, the quantity moving on that trade route would increase by the amount listed under volume increase. If this amount were small, the change would be tightly bound by other restrictions. For the dissolving pulp example, only 499 MT could be added to this trade.

Information on the wood-chip trade with the Pacific Northwest indicated that the resource rent could drop $3.71 with no effect on trade levels. This is the difference between the 1982 export price for chips and the resource rent for this trade route. The simulation also indicated that no expansion of trade would occur as a result of low 1982 market activity. Chip trade is largely dependent on the volume of timber processed. In poor market years, most wood chips are used in the pulping process. In better years, chips are available for export as more timber is processed and pulping needs are met.

In contrast, the model's solution for the sulphite pulp barge trade with the Pacific Northwest was at the highest level possible. Trade expansion was fully limited by other constraints. Reducing the volume traded would allow increased trade on other routes, but at reduced rent gains. No better market price existed than this $280.61 resource rent. Any unit reduction after relaxing the Jones Act would decrease the total resource rent by this amount, up to a total change of 1,391 MT.

Table 7—Shadow prices, highest market prices, and increases in volume resulting from sensitivity analysis of the major affected trade flows, 1982

Product	Units	Final destination	Transportation mode	Resource rent	Shadow price 1/	Highest market price	Volume increase
				- - - - - -$/unit- - - - - -			unit
Dissolving pulp	MT	Pacific NW	Tug and barge	454.61	141.39	596.00	499
Sulphite pulp	MT	Pacific NW	Tug and barge	280.61	-280.61	0	-1,391
Wood chips	MT	Pacific NW	Tug and barge	64.71	-3.71	61.00	0
Spruce cants	MBF	Pacific NW	Container ship	718.81	-.68	718.13	-2,918
Hemlock dimension	MBF	Interior	Tug and barge	177.52	163.48	341.00	0
Hemlock No. 2 logs	MBF	Pacific NW	Tug and barge	312.16	237.84	549.99	2,324
Pulpwood	MBF	SE Alaska	Tug and barge	140.52	.18	140.70	60,000
Pulpwood	MBF	SE Alaska	Tug and raft	128.70	12.00	140.70	69,150
Pulpwood	MBF	Pacific NW	Tug and barge	140.70	-.18	140.52	-60,000

NW = northwest; SE = southeast.

1/ Represents the necessary change in the non-Jones Act resource rent to change the solution.

The pulpwood trade provided an interesting study of model interactions. The Jones Act simulation moved all the surplus Native pulpwood within southeast Alaska by tug and raft. This was not closely correlated to actual 1982 trade patterns, as harvesting Native pulpwood was uneconomical and much was left in the woods. Local movements are, however, the most probable routes that would be utilized under better economic conditions. Relaxing the Jones Act caused the greatest change in the resource rent in the tug and barge route from southeast Alaska to the Pacific Northwest. Consequently, all 69,150 MBF of Native pulpwood shifted into the Pacific Northwest market at the new resource rent of $140.70. The shadow price revealed that this commodity is very sensitive to price changes. An $0.18 decrease in price would shift pulpwood back into the southeast Alaska market.

Validation of the model was done during the sensitivity analysis. All supply, capacity, and demand constraints were tested to establish their limits. In addition, the highest market price behavior and the barge-container ship modal switches were tested. Details of these test results are presented in Jackson (1984).

Conclusions

All three study objectives were met. Differential freight rates do exist on Alaska transportation routes. These differences were measured for all Alaska forest products on the major modes and routes. Second, the effects of the Jones Act on direction of trade was measured, although at a low level. Finally, the losses incurred by forest products consumers and producers in Alaska were calculated for the analysis period. From this, we can reject the hypothesis that the Jones Act had no effect on forest products trade in Alaska in 1982.

Our major conclusion is that the Jones Act does affect the Alaska forest products trade. The total 1982 reduction in producer and consumer wealth in Alaska was approximately $4.77 million. However, little change in the level of trade of individual products or in final market destinations occurred after relaxing the Jones Act. The effects of the Jones Act were small and transportation rate changes did not appear to be a major factor in market determination.

The results of this study agreed with most of the previous research on the Jones Act. The conclusion that the Jones Act alone does not impede market access was made by Austin and Darr in 1975. Confirming that transportation cost changes can shift markets if no other constraints are binding is consistent with the findings of the U.S. Senate (1970). As Morgan (1980) concluded, the long run response to the Jones Act is to concentrate on unconstrained export markets. Boyd (1981) reached the conclusion that the economic effect of the Jones Act on the softwood lumber industry in the lower 48 States is small and insignificant. Our findings for Alaska concurred.

Low-value products and the longer trade routes exhibited greater sensitivity to changes in transportation costs. These products and routes were more sensitive to rate changes because transportation costs constituted a greater proportion of total costs. Where equal transportation rates existed between two competing modes for the same product-route combination, modal shifts were sensitive to rate changes.

Differences in final market price appeared to have more control over final destination than did transportation cost changes for all but the lowest valued products. High-valued products, such as pulp, lumber, and cants, continued to move overseas, unaffected by the Jones Act. Large price changes in these products were required to divert volume to domestic markets. This supported the theory that Alaska's comparative advantage is in Pacific Rim countries.

As a greater volume of Native timber is harvested and available for export, more pulpwood will be jointly produced (Mehrkens 1983). Reducing the freight rate appeared to increase volumes moving to the lower 48 States. Recent market activity has included shipments of better grades of Alaska "pulpwood" to the Pacific Northwest in response to higher hemlock log prices and shrinking supplies. For the same reasons, chips, spruce cants, and hemlock cants also may have market possibilities there. Relaxing the Jones Act improved Alaska competitiveness only slightly in the Pacific Northwest, but generally not enough to open new markets and shift trade flows.

Any changes in Alaska forest products transportation rates will result in gains to the producers and consumers and losses for the shipping services. We represented these gains and losses as instantaneous: windfall profits to timber growers and consumers in Alaska and losses to the shippers with U.S.-built vessels. Actually, the $4.77-million 1982 effect of the Jones Act, and subsequent annual effects, would appear gradually as competitors offering lower costs enter the transportation market. There would be an instant loss related to the monopoly equity of existing U.S.-built vessels, but full transition to unrestricted domestic trade for the Alaska forest industry and the shipping industry would not be instantaneous.

Our conclusions were drawn from the sample data for 1982, which represented a low volume year. Under improved market conditions, the transportation differential may not change much and should become an even smaller proportion of rising product prices. The major increase in annual impacts from the Jones Act would come from increases in price-responsive internal movements of roundwood.

Testing the effects of the Jones Act under poor market conditions should show the economic conditions that are most likely to generate trade shifts. In better markets, trade diversion may be even more unlikely. However, in the event of constrained timber supplies or other institutional changes in the Pacific Northwest and British Columbia, trade diversion may become possible.

The long-run implications of relaxing the Jones Act in the Alaska forest products trade, although small, are several. Over time, the resource rents returning to timber producers could increase, while those of shippers with existing U.S.-built vessels in their fleets may fall. As these vessels are retired, the operators will again receive returns comparable to those received by their competitors using foreign-built vessels. Thus, altering the Jones Act will favor operators with fleets near retirement age and new entrants in the shipping business.

Alaska consumers will benefit as the prices of construction materials fall with changing freight rates. The short-run effect is to increase consumer savings, while in the long run, housing costs could drop slightly.

Altering the Jones Act could improve service in Alaska trade. As technological innovations become available in world shipping markets, an unrestrained Alaska shipping industry would be free to supply new services, which would improve the well being of both industries. Relaxing the Jones Act would help the Alaska forest products industry become more competitive with adjacent timber supply regions (British Columbia and the Pacific Northwest), and new trade patterns could eventually develop.

Metric and English Equivalents

Logs and lumber:
1,000 board feet, Scribner log scale (MBF) = 4.53 cubic meters (m^3)
1,000 board feet, Scribner lumber tally (MBF) = 2.36 cubic meters (m^3)
1,000 board feet, Scribner lumber tally (MBF) = 1.7 Brereton MBF
1,000 board feet, Scribner lumber tally (MBF) = 0.521 MBF, log scale
1 40-foot container = 13-15 MBF, lumber tally
1 20-foot container = 6-8 MBF, lumber tally

Pulp and chips:
1 air-dry short ton (ADST) pulp = 2,000 pounds (lb)
1 metric ton (MT) = 0.90718 short ton
1 ADST = 1.1023 air dry metric ton pulp (ADMT)
1 bone-dry ton pulp (BDT; ALP) = 2,000 pounds (lb)
1 BDT = 1.0886 metric ton
1 bone-dry unit pulp (BDU; LPK, Canada) = 2,400 pounds (lb)
1 BDU = 96 cubic feet (ft^3) western hemlock chips
1 MT western hemlock chips = 2.497 cubic meters (m^3)
1 ADST pulp = 2.06 BDU chips

Other:
1 meter (m) = 3.28 feet
1 square meter (m^2) = 10.76 square feet (ft^2)
1 cubic meter (m^3) = 35.314 cubic feet (ft^3)
1 hectare = 2.47 acres

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Appendix 1

1982 Alaska Forest Products Trade Flows

Examples of 1982 Alaska forest products trade flows are included here (tables 8-14). These tables explain the trade flows for the active 1982 product-route combinations. Each table contains the route distance, the 1982 Jones Act freight rates for all active modes, the average product price, and the total volume moved in 1982. The aggregated product price is the resource rent proxy used in the analysis, as is the volume moving at this price.

Table 8—1982 freight rates, product prices, and volumes moved, for western hemlock No. 2 logs, on bulk carriers

Route	Route distance	Bulk carrier freight rate	Product price	Volume moved in 1982 1/
	miles	$/MBF	$US F.O.B.	MBF
Alaska to Japan	4,055	90	350	119,927
Alaska to Republic of Korea	4,015	94	2/ 434	4,134
Alaska to Pacific Northwest	728	3/ 72	300	58
British Columbia to Republic of China	4,650	4/ 93	5/ 199	887
British Columbia to Japan	4,293	87	5/ 235	51,389
British Columbia to Pacific Northwest	252	3/4/ 25	5/ 199	23,241
Pacific Northwest to People's Republic of China	5,185	99	300	18,984
Pacific Northwest to Republic of China	4,650	4/ 97	253	2,721
Pacific Northwest to Japan	4,293	93	380	647,002
Pacific Northwest to Republic of Korea	4,520	100	260	206,183
Pacific Northwest to British Columbia	252	3/4/ 25	230	1,841
Southeast Alaska 6/	150	7/ 18	NA	144,595
Southeast Alaska 6/	150	3/ 45	NA	6,487

NA = not available.

1/ Volume includes all log grades.
2/ Source: U.S. Department of Commerce (1982).
3/ Tug and barge movement.
4/ Estimate based upon actual market situation.
5/ Source: Statistics Canada (1982).
6/ Internal movements calculated for the submodel.
7/ Tug and raft movement.

Table 9—1982 freight rates, product prices, and volumes moved, for Sitka spruce cants, on bulk carriers and container ships

Route	Route distance	Bulk carrier freight rate	Container ship freight rate	Product price	Volume moved in 1982
	miles	$/MBF	$/MBF	$US F.O.B.	MBF
Alaska to People's Republic of China	4,295	1/ 80	1/ 80	2/ 344	3/ 9,846
Alaska to Japan	4,055	57	81	410	3/ 83,966
Alaska to Republic of Korea	4,015	107	107	520	3/ 993
Southeast Alaska (internal)	150	4/5/ 7	NA	347	3/ 4,491
Alaska to Pacific Northwest	728	5/ 27	27	713	3/ 2,653
British Columbia to People's Republic of China	5,185	80	50	426	6/ 624
British Columbia to Japan	4,293	66	57	426	6/ 64,706
Pacific Northwest to Japan	4,293	70	81	548	4,844
Pacific Northwest to Republic of Korea	4,520	90	93	548	2,593
Pacific Northwest to British Columbia	252	5/ NA	NA	6/ 363	164

NA = Not available.

1/ Estimate based upon actual market conditions.
2/ Source: U.S. Department of Commerce (1982).
3/ Volume includes all rough lumber (clears and cants).
4/ Calculated for analysis.
5/ Tug and barge movement.
6/ Volume includes rough and dressed lumber (clears, dimension, and cants).

Table 10—1982 freight rates, product prices, and volumes moved, for western hemlock dimension lumber, on bulk carriers and container ships

Route	Route distance	Bulk carrier freight rate	Container ship freight rate	Product price	Volume moved in 1982
	miles	$/MBF	$/MBF	$US F.O.B.	MBF
Alaska to Japan	4,055	57	81	341	1/ 453
Alaska to Republic of Korea	4,015	107	107	2/ 495	1/ 1,001
Southeast Alaska to interior Alaska	610	3/ 29	NA	4/ 172	1/ 0
Southeast Alaska (internal)	150	3/5/ 7	NA	172	1/ 49
British Columbia to People's Republic of China	5,185	80	50	361	6/ 28,877
British Columbia to Japan	4,293	66	57	361	6/ 771,181
British Columbia to Pacific Northwest	252	3/ NA	NA	188	6/ 683,888
Pacific Northwest to Japan	4,293	70	81	271	1/ 142,574
Pacific Northwest to Republic of Korea	4,520	90	93	350	1/ 50
Pacific Northwest to British Columbia	252	3/ NA	NA	335	1/ 5,008

NA = not available.

1/ Volume includes all rough lumber (clears and cants).
2/ Source: U.S. Department of Commerce (1982).
3/ Tug and barge movement.
4/ Estimate based upon actual market situation.
5/ Calculated for analysis.
6/ Volume includes rough and dressed lumber (clears, dimension, and cants).

Table 11—1982 freight rates, product prices, and volumes moved, for dissolving pulp, on bulk carriers and container ships

Route	Route distance	Bulk carrier freight rate	Container ship freight rate	Product price	Volume moved in 1982
	miles	$/ADMT	$/ADMT	$US F.O.B.	ADMT
Alaska to People's Republic of China	4,925	1/ 75	1/ 80	2/ 419	14,449
Alaska to Republic of China	3,895	65	1/ 77	2/ 505	7,249
Alaska to Japan	4,055	66	1/ 70	596	94,278
Alaska to Republic of Korea	4,015	81	77	677	339
Alaska to India	8,834	99	1/ 100	2/ 458	7,525
Alaska to British Columbia	476	1/3/ 15	NA	2/ 490	150
Alaska to Pacific Northwest	728	3/ 19	NA	2/ 451	24,177
British Columbia to People's Republic of China	5,185	45	1/ 80	4/ 442	6,294
British Columbia to Republic of China	4,650	42	1/ 77	4/ 416	9,076
British Columbia to Japan	4,293	42	1/ 75	4/ 503	5,695
British Columbia to Republic of Korea	4,520	42	77	4/ 629	427
British Columbia to India	9,148	1/ 50	1/ 90	4/ 425	6,581
British Columbia to Pacific Northwest	252	1/3/ 10	NA	4/ 524	9,740
Pacific Northwest to Republic of China	4,650	60	1/ 77	445	5,805
Pacific Northwest to Japan	4,293	56	75	730	49,572
Pacific Northwest to Republic of Korea	4,520	63	1/ 77	675	10,297

NA = not available.

1/ Estimate based upon actual market conditions.
2/ Source: U.S. Department of Commerce (1982).
3/ Tug and barge movement.
4/ Source: Statistics Canada (1982).

Table 12—1982 freight rates, product prices, and volumes moved, for sulphite pulp, on bulk carriers and container ships

Route	Route distance	Bulk carrier freight rate	Container ship freight rate	Product price	Volume moved in 1982
	miles	$/ADMT	$/ADMT	$US F.O.B.	ADMT
Alaska to Japan	4,055	66	1/ 70	2/ 427	205
Alaska to India	8,834	99	1/ 100	430	1,637
Alaska to British Columbia	476	1/3/ 15	NA	2/ 328	296
Alaska to Pacific Northwest	728	3/ 19	NA	277	4,036
British Columbia to Republic of China	4,650	42	1/ 77	4/ 518	5,271
British Columbia to Japan	4,293	42	1/ 75	4/ 530	5,882
British Columbia to Republic of Korea	4,520	42	77	4/ 519	571
British Columbia--Hong Kong	5,795	1/ 45	1/ 80	4/ 499	75
British Columbia to Pacific Northwest	252	1/3/ 10	NA	4/ 480	9,868
Pacific Northwest to British Columbia	252	1/3/ 10	NA	2/ 441	1,138
Pacific Northwest to Republic of China	4,650	60	1/ 77	2/ 392	4,121
Pacific Northwest to Japan	4,293	56	75	2/ 459	43,381
Pacific Northwest to Republic of Korea	4,520	63	1/ 77	2/ 473	7,567
Pacific Northwest to Hong Kong	5,795	1/ 58	1/ 80	2/ 351	2,088
Pacific Northwest to India	9,148	1/ 60	1/ 90	2/ 509	1,637

NA = not available.

1/ Estimate based upon actual market conditions.
2/ Source: U.S. Department of Commerce (1982).
3/ Tug and barge movement.
4/ Source: Statistics Canada (1982).

Table 13—1982 freight rates, product prices, and volumes moved, for wood chips, on tug and barge and conference carriers

Route	Route distance	Tug and barge freight rate	Conference carrier freight rate	Product price	Volume moved in 1982
	miles	$/ADMT	$/ADMT	$US F.O.B.	ADMT
Alaska to Japan	4,055	NA	217	61	67,280
Alaska to British Columbia	476	1/ 25	NA	61	0
Alaska to Pacific Northwest	728	1/ 50	NA	61	0
British Columbia to Japan	4,293	NA	217	61	396,654
British Columbia to Alaska	476	1/ 25	NA	61	2/ 734,869
British Columbia to Pacific Northwest	252	1/ 25	NA	64	2/ 734,869
Pacific Northwest to Japan	4,293	NA	217	80	2,029,821
Pacific Northwest to British Columbia	252	25	NA	64	4,757
Pacific Northwest to Alaska	728	1/ 50	NA	64	0
Pacific Northwest to Pacific Northwest	150	NA	NA	64	NA
Southeast Alaska (internal)	150	3/ 12	NA	55	209,523

NA = Not available.

1/ Estimate based upon actual market conditions.
2/ Includes exports to Alaska and the Pacific Northwest.
3/ Internal movement calculated for the submodel.

Table 14—1982 freight rates, product prices, and volumes moved, for pulpwood, on bulk carriers

Route	Route distance	Bulk carrier freight rate	Product price	Volume 1/ moved in 1982
	miles	$/MBF	$US F.O.B.	MBF
Southeast Alaska (internal)	150	2/ 27	3/ 127	4/ 14,522
Southeast Alaska (internal)	150	5/ 27	3/ 127	4/ 97,902
Alaska to Pacific Northwest	728	2/ 72	3/ 127	0
British Columbia to Alaska	476	2/ 25	122	6/ 87
British Columbia to Pacific Northwest	252	2/7/ 25	122	6/ 87
Pacific Northwest to British Columbia	252	2/7/ 25	86	1,759

NA = not available.

1/ Volume includes all pulp species.
2/ Tug and barge movement.
3/ Calculated for analysis.
4/ Internal movements calculated for the submodel.
5/ Tug and raft movement.
6/ Estimate based upon actual market situation.
7/ Source: Statistics Canada (1982). Volume shipped to U.S.

Appendix 2

The Partial Equilibrium Model

The partial equilibrium model set X_{ijk} to represent the nonnegative volume of commodity k shipped from supplier i to demand region j. R_{ijk} is the resource rent per unit of commodity k for shipment between the i^{th} supplier and the j^{th} demand region. Only when i = Alaska are these rents other than zero. Thus, R_{ijk} represents the unique rent that can be derived from delivered price and shipping costs for Alaska forest products. The total resource rent is the sum of individual rents for all trade flows across all Alaska suppliers, destinations, and commodities. The effects of relaxing the Jones Act appear in a second simulation where R_{ijk}'s affected by the Jones Act are increased by the cost differential.

The supply and demand regions used in this model are:

Supply region

Southeast Alaska
British Columbia
Pacific Northwest

Demand region

Southeast Alaska
Pacific Northwest
British Columbia
Interior Alaska
Japan
Republic of Korea
People's Republic of China
Republic of China
India
Hong Kong

The form of the resource rent model used in this analysis is as follows:

Maximize Alaska resource rents:

$$Z = \sum_{i=1}^{l} \sum_{j=1}^{m} \sum_{k=1}^{n} R_{ijk} \quad X_{ijk};$$

where: i=1 to l suppliers,
j=1 to m demanders, and
k=1 to n commodities.

Subject to:

Supply constraint:

$$\sum_{j=1}^{m} \sum_{k=1}^{n} X_{ijk} \geq S_{ik},$$

where: S_{ik} = production level of supplier i for commodity k.

Capacity constraint:

$$\sum_{j=1}^{m} \sum_{k=1}^{n} X_{ijk} \leq C_{ik}$$

where: C_{ik} = capacity level of supplier i for commodity k.

Demand constraint:

$$\sum_{i=1}^{l} \sum_{k=1}^{n} \quad (1.1) \quad X_{ijk} = D_{jk},$$

where: D_{jk} = requirements of demand region j for commodity k.

Nonnegativity constraint:

The nonnegativity constraint was modified to represent 1982 movements. Thus, shipments were set greater than or equal to the 1982 volume of trade:

$$X_{ijk} \geq M_{ijk}$$

where: M_{ijk} = actual 1982 trade volume from supplier i to demand region j for commodity m.

This did not bias the second simulation, as under the Jones Act, exports to the lower 48 States are almost nonexistant.

Two coefficient matrices were used in the model. The first contained transportation costs affected by the Jones Act; the second tested the effects of an immediate shift to transportation rates unaffected by the Jones Act. Each matrix groups, by commodity, all information for each route. Matrix size is defined by 10 Alaska forest product trade destinations, 6 possible carrier types, 6 commodities, and 2 timber species. Each data matrix contains over 400 route/product/mode variables and about 250 supply, demand, and capacity constraints (Jackson 1984).

Glossary

Backhaul—A return voyage to the home port, often at a reduced freight rate to avoid travel in ballast.

Break-bulk—Cargo packed in separate packages, in many consignments, or as individual pieces of cargo. Packages are loaded, stowed, and unloaded individually; as distinct from bulk cargo.

Bulk carriers—Ship designed to carry bulk, nonliquid cargo.

Cabotage—Coastal maritime transportation within one country and restricted to vessels of domestic registry.

Cant—A log squared on four sides to reduce stowage or to circumvent local manufacturing restrictions. (See also Waney.)

Coastwise—A shipping service between ports on the same coast.

Common carriers—Any vessel or person presented to the general public as ready, able, and willing to engage in interstate or foreign commerce, with passengers or property of any class(es), for compensation.

Conference (liner or steamship)—A combination (technically, a cartel) of shipping companies or owners that sets common liner freight rates on a particular route and that regulates the provision of services.

Constraint—Usually, a mathematical relationship between the decision variables of an optimization problem in which some function of the variable is not equal to a constant. An example is the timber supply constraint on the maximization of lumber production.

Containers—Standard units of cargo packaging similar in size to truck trailers, but lacking wheels. Commonly 20-foot or 40-foot lengths. (See also Break-bulk.)

Container ship—A ship designed to carry containerized cargo.

Derived demand—Demand for a factor of production is derived from the demand for the final goods that the factor cooperates in producing.

Dry bulk—Cargoes that can be placed aboard ship unpackaged, such as wood chips and mineral ores, and that can be handled by highly automated loading equipment; usually carried in full shipload lots.

DWT (dead weight tonnage)—The weight in long tons (2,240 pounds) that a vessel can carry when fully loaded.

Equilibrium—A situation in which, in the aggregate, buyers and sellers are satisfied with the current combination of prices and quantities bought or sold, and so are under no incentive to change their present actions.

F.O.B. (free on board)—The value of the goods, including the value of packing, when placed on board the vessel. It includes such charges as those the shipper paid to the port, but excludes cargo insurance and freight; roughly corresponds to market value in the exporting country.

Foreign-flag—A vessel licensed and operated under the rules and taxation system of a foreign state. (See also U.S.-flag.)

General cargo—Cargo consisting of individual units or packages (parcels) that are not homogeneous in bulk.

Indirect and induced effects—In an economy, secondary and subsequent effects that result from some primary change in the equilibrium. For example, a change in the Jones Act can result in obvious changes in waterborne transportation employment that "ripple down" to changes in new construction employment.

Input-output (I/O)—A method of analysis in which the economy is represented by a set of linear production functions that describe the interrelationships between all sectors. Thus the total output of each sector is split into the amounts that are used in the production of all other commodities (intermediate production) and those finally consumed.

Intercoastal—Domestic trade between national coasts in two or more seas.

Intermodal—The concept of transportation as door-to-door, rather than point-to-point. The movement of goods is coordinated among different modes to insure rapid and efficient transportation.

Jones Act—Legislation allowing only U.S.-built, U.S.-owned, and U.S.-registered ships in U.S. domestic ocean trades. Specifically, Section 27 of the Merchant Marine Act of 1920.

Jones Act, effects—Increased costs of U.S. domestic waterborne trade due solely to the enforcement of the Jones Act.

Linear programming—A technique for formalizing and analyzing constrained optimization problems in which the objective function is a linear function and is to be maximized or minimized subject to a number of linear inequality constraints.

Margin change—A shift in the derived demand and derived supply functions for a product resulting from a change in the cost of providing existing marketing service and subsequent changes in both retail and producer prices. An increase will cause declines in derived demand (downward shift) and derived supply (upward shift), resulting in an increase in retail price, a decrease in the producer price, and a wider margin.

Net returns (profits)—That portion of total profits that remains after the deduction of taxes and depreciation provisions.

Partial equilibrium—The study of a market for a commodity in isolation. Given the prices of all other commodities, the conditions for equilibrium in a single market are examined.

Raft (log raft)—A form of water transport of logs where boom sticks (logs) are chained together so as to surround the logs being towed. Flat rafts and bundle rafts are the most common types. Flat rafts allow the logs to float freely within the boom sticks and are often used in lakes or large rivers. In adverse conditions, a truckload or group of logs is bundled prior to rafting. These bundle rafts are used in the ocean to prevent log loss, to carry along sinkers, and to move small logs more efficiently.

Resource rent—A payment to a natural resource in excess of what is necessary to keep it in its present usage. This is the difference between what the resource currently receives and the next best alternative.

Sensitivity analysis—Changing the parameters of a problem and studying how this affects the outcome. The purpose is to identify the important assumptions the analysis is based on—those to which the outcome is sensitive.

Shadow price—A calculated valuation of a commodity that has no market price. Shadow prices represent a commodity that is generally not traded in the economy. To the extent that market prices do not reflect opportunity costs, shadow prices may be substituted.

Simulation—A form of forecasting that generates a range of alternative projections based on various assumptions about future situations, specifically to answer the question, "What would happen if?" rather than "What will happen?"

U.S.-flag—A vessel owned and operated under the rules and taxation system of the United States of America. Such a vessel is subject to the Jones Act when engaged in domestic trade.

Waney—A log squared on two sides to facilitate storage onboard ship or to meet local manufacturing requirements. (See also Cant.)

Jackson, Kristine C.; McKetta, Charles W. Impacts of the Jones Act on the Alaska forest products trade. Gen. Tech. Rep. PNW-196. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 39 p.

Alaska forest products trade flows for 1982 were studied to determine the effects of the Merchant Marine Act of 1920 (the Jones Act). Information was collected from timber producers, forest product industries, and waterborne shippers in Alaska, British Columbia, and the Pacific Northwest. Trade flows were simulated, using a partial equilibrium model based on resource rents, with and without the Jones Act restrictions.

Results indicate that $4.77 million in additional costs were incurred in 1982 because of the Jones Act. These effects appeared small, however, relative to the wholesale value of trade. Further, the Jones Act cost differential was not a major factor in market determination, although low-value products and longer trade routes were more sensitive to cost changes. Primary movements of logs and chips and lumber imports from the Pacific Northwest showed the greatest potential for cost savings after relaxing the Jones Act.

Keywords: Jones Act, trade balance, markets (external), forest products carriers, economics (forest transport), Alaska (southeast), southeast Alaska.

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Pacific Northwest
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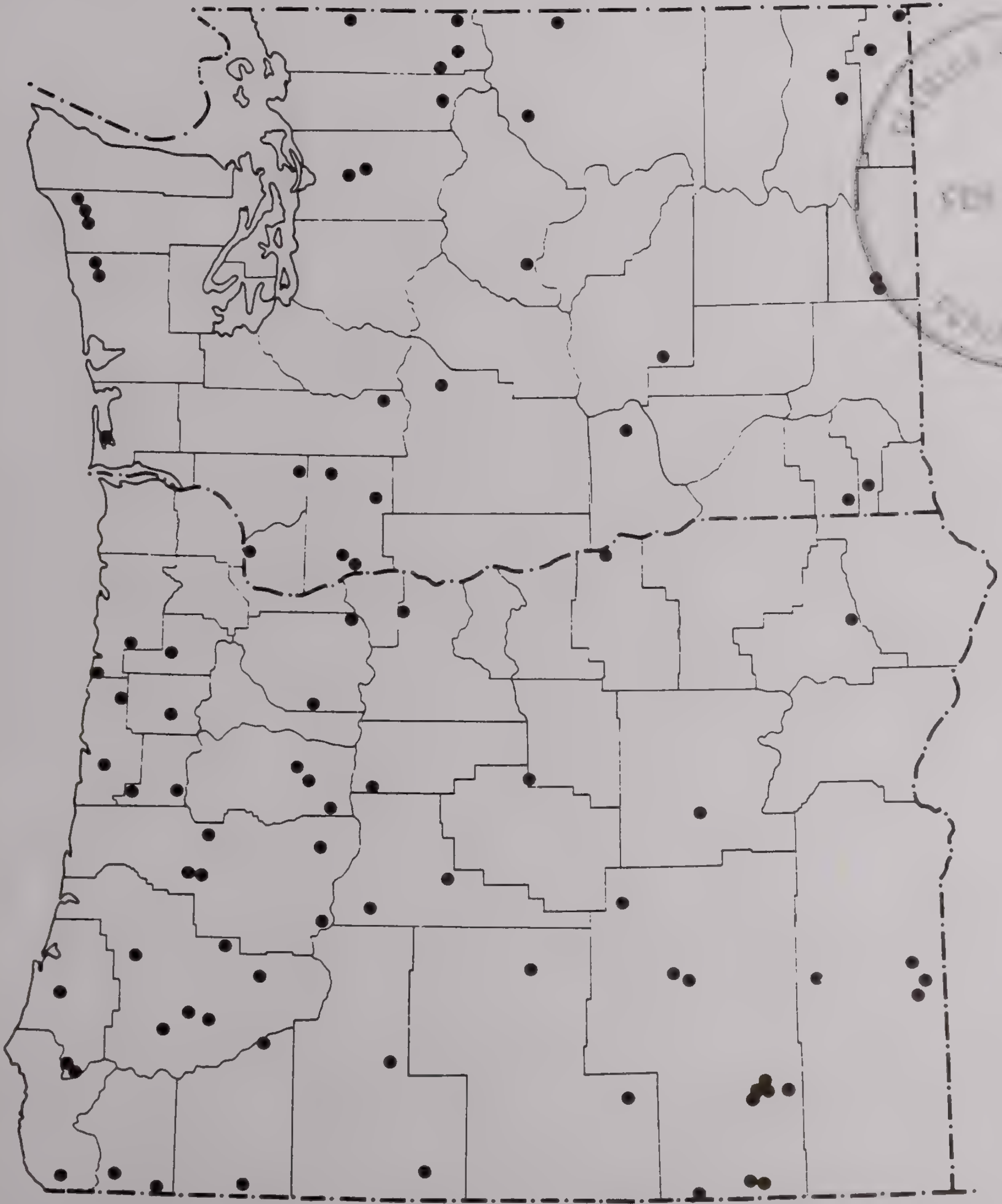
General Technical
Report
PNW-197

November 1986

Research Natural Areas in Oregon and Washington: Past and Current Research and Related Literature

Sarah E. Greene, Tawny Blinn, and Jerry F. Franklin



Authors

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Foreword

In 1971, I joined the Pacific Northwest Forest and Range Experiment Station as Station Director and, among other duties, became chairman of the Interagency Committee on Research Natural Areas. It was a chair that I held for 4 years, and it is a pleasure to reflect, more than 10 years later, on the progress that has been made.

Oregon and Washington already had a vigorous program of preservation of Natural Areas for scientific and educational purposes in 1971. In preparation at that time were several publications important to identifying and protecting Natural Areas, including a description of natural vegetation of Oregon and Washington (Franklin and Dyrness 1973), an inventory of Federal Research Natural Areas in Oregon and Washington (Franklin and others 1972),[1/] and a comprehensive inventory of Natural Areas recognized by the Society of American Foresters (Buckman and Quintus 1972).

The Interagency Committee, with participation from The Nature Conservancy and the States of Oregon and Washington then asked, "What should a well-balanced program of Research Natural Area preservation include?" This led to the publication, "Research Natural Area Needs in the Pacific Northwest: A Contribution to Land-Use Planning" (Dyrness and others 1975). Today there are 96 Research Natural Areas in the Northwest, and others are being considered by cooperating Federal and State agencies and private organizations in a well-coordinated and visionary program.

[1/] "Federal Research Natural Areas in Oregon and Washington: A Guidebook for Scientists and Educators" contains descriptions of 45 of the 48 Research Natural Areas on Federal land in 1972. Since the guidebook was published, 24 supplements, each describing a Research Natural Area, have been published. Supplement 13 (Greene 1982) revised the description of Neskowin Crest RNA given in the guidebook because the area was enlarged in 1980.

The need to encourage and stimulate the use of these areas for scientific and educational purposes was recognized in the early 1970's. Even then, some research was underway. But today, in 1986, large gains have been made in the visibility and use of Research Natural Areas. And that is the purpose of this publication--to take stock of the information garnered from Research Natural Areas and the ongoing research. This publication addresses one of the questions that will assure a well-rounded and responsible system of Research Natural Areas for the Northwest: What use has been made and is being made of Research Natural Areas?

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Abstract

Greene, Sarah E.; Blinn, Tawny; Franklin, Jerry F. Research Natural Areas in Oregon and Washington: past and current research and related literature. Gen. Tech. Rep. PNW-197. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 1986. 115 p.

This publication lists all completed and current research projects in Research Natural Areas in Oregon and Washington and in those few Research Natural Areas in Idaho that are administered by National Forests in Oregon. The list includes project title, status, source of funding, and principal investigator and address. A list of publications pertaining to Research Natural Areas is also included. Where possible, publications and research projects are correlated. The publication outlines the scientific use and importance of Research Natural Areas as research sites for applied and basic studies. More than 200 projects and 500 publications are included for 88 Research Natural Areas and 23 proposed Research Natural Areas.

Keywords: Natural areas (research), bibliographies (research natural area), land management, research.

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Key to Abbreviations

BLM - U.S. Department of the Interior, Bureau of Land Managemen
DOD - U.S. Department of Defense, Navy
DOE - U.S. Department of Energy
FS - U.S. Department of Agriculture, Forest Service
FWS - U.S. Department of the Interior, Fish and Wildlife Servic
NPS - U.S. Department of the Interior, National Park Service
NSF - National Science Foundation
RNA - Research Natural Area

Objectives of Research Natural Areas

A Research Natural Area (RNA) is a physical or biological unit or both, in which natural conditions are maintained insofar as possible by letting natural physical and biological processes prevail without human intervention (Federal Committee on Ecological Reserves 1977). In some circumstances, human intervention may be justified to maintain the feature for which the RNA was set aside. The introduction of prescribed fire in seral stands historically maintained by fire is an example.

The objectives for establishing RNA's are:

- To preserve examples of all significant natural ecosystems for comparison with those influenced by humans.
- To provide educational and research areas for ecological and environmental studies.
- To preserve gene pools for typical and rare and endangered plants and animals.

In 1928, the Forest Service established the first RNA, the Santa Catalina Natural Area, on the Coronado National Forest in northern Arizona. Since then, the program has grown nationwide and has included designations by other Federal agencies and cooperation with State natural area programs and The Nature Conservancy.

Research Natural Area Program in the Pacific Northwest

The Research Natural Area program in Oregon and Washington was begun in 1931 when the Metolius RNA was established on the Deschutes National Forest in Oregon. To date (1986), 96 RNA's in Oregon and Washington on Federal lands are managed by the U.S. Department of Agriculture--Forest Service; the U.S. Department of the Interior--Bureau of Land Management, National Park Service, and Fish and Wildlife Service; the U.S. Department of Defense--Navy; and the U.S. Department of Energy. Management differs somewhat between agencies, but the agencies all concur on the objectives for RNA's. An interagency committee meets twice a year to conduct RNA business and discuss common problems.

Scientific use of RNA's has always been encouraged in Oregon and Washington. Research Natural Areas provide useful and essential information to land managers as well as contribute to basic science. Research activities must be essentially nondestructive, and the scientific and educational values of the areas must not be impaired. Each agency has a set of guidelines for use, but none is particularly restrictive as long as the essential characteristics and processes of the RNA's are maintained.

Purpose of the Publication

The research conducted on RNA's in the Pacific Northwest includes forest site productivity, plant community classification air pollutant monitoring, measurement of environmental parameters like air and soil temperature, nutrient cycling, role of woody debris in forest ecosystems, succession, grazing effects, and litter decomposition rates, as well as other types of research. A research project may last from several days to more than 50 years. Research on seedling survival in the Thornton T Munger RNA in southern Washington was begun in the early 1930's Also at Thornton T. Munger RNA, a study of the growth, yield, and mortality of an old-growth Douglas-fir--western hemlock forest was begun in 1947, and measurements are still being taken. Many publications have resulted from this study, and the plot information has been used in recent studies both inside and outside the RNA.

Some research in RNA's complements manipulative research being done in nearby or adjacent Experimental Forests, including the Cascade Head, H.J. Andrews, and Wind River Experimental Forests for example, sediment routing in the undisturbed watershed of the Hagan proposed RNA has been compared with sediment routing in several disturbed watersheds in the nearby H.J. Andrews Experimental Forest. The dynamics of riparian vegetation have been studied in the Hagan proposed RNA and Middle Santiam RNA (100- and 450-year-old stands, respectively) and compared with the dynamics of riparian vegetation along streams in 40- and 5-year-old clearcuts in the H.J. Andrews Experimental Forest.

Several research projects have been conducted in RNA's throughout Oregon and Washington. The distribution and role of conif needle endophytes were studied in 27 RNA's. Ecological monitoring of long-term effects of energy development has been studied in RNA's in the Oregon Coast Range, the Cascade Range in western Oregon, the High Lava Plains, and the Columbia Basi geographical provinces.

Interest and work in RNA's have increased dramatically in the last 15 years. Despite this increase, the value of RNA's is not adequately recognized by land managers. Without baseline information on natural systems, we cannot be sure what effects our management practices may have on the productivity of the land. As Federal agencies begin monitoring their management plans, though, RNA's should play an increasingly important rol as baselines for comparison.

Many researchers and academicians, as well as land managers, are not aware of the existence of RNA's. Those who use RNA's need additional funds to conduct research in them. Support for past work has come from a variety of sources, primarily Federal and university. Sometimes private and even personal funds have been used. A paucity of funding continues, however.

This publication identifies more than 200 research projects that have been conducted during the 55-year history of the program. More than 500 publications relating to RNA's are also included. We hope this publication will make researchers and land managers more aware of the large contribution RNA's have made to science and to better land management in the Pacific Northwest.

Organization of This Publication

Research Natural Areas are listed in alphabetical order. Research projects conducted at each RNA are listed next and numbered. Information about each research project is given in the following order:

Title of research project
Status of project (current or completed, with initiation and completion date if applicable)
Source of funding
Principal investigator and address

Scientific papers resulting from research conducted at the RNA are listed next, by author and date, and the complete references are given in "References." Numbers in parentheses indicate that such papers resulted from the corresponding research project.

The appendix lists RNA's by State and managing agency.

Research Projects and Related Literature

Abbott Creek RNA, Rogue River National Forest, OR (FS)

1. Composition and distribution of southwestern Oregon mixed-conifer forests
   Completed; 1969-76
   Oregon State University
   Rod Mitchell, Colorado Women's College, Denver, CO 80220

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Ecological site classification of southwestern Oregon
   Current; 1981
   FS and BLM
   Bradley Smith, Forest Science Department, Oregon State University, Corvallis, OR 97331

4. Flora of the Abbott Creek RNA
   Completed; 1969-79
   Pacific Northwest Natural Area Committee
   Rod Mitchell, Colorado Women's College, Denver, CO 80220

5. Genetic variation in the noble-red fir complex
   Current; 1967
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

6. Vegetation classification of old-growth wildlife habitat
   Current; 1983
   FS
   Tom Spies, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Carroll and Carroll 1978 (2); Franklin and Dyrness 1973; Franklin and others 1972; Mitchell 1972 (1, 4), 1979 (1, 4); Mitchell and Moir 1976 (1, 4); Old-Growth Definition Task Group 1986 (6); Spies and others 1985 (6); Vale 1981.

Alum Beds Proposed RNA, Nez Perce National Forest, ID, administered by Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of grasslands/shrublands
   Current; 1982
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Ashland RNA, Rogue River National Forest, OR (FS)

1. Community types of the Siskiyou Mountain Province
   Current; 1975
   FS
   Tom Atzet, Siskiyou National Forest, Grants Pass, OR 97526

2. Cone and seed crop production by mixed-conifer forests
   Current; 1982
   FS
   Sarah Greene, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

3. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

4. Ecological site classification of southwestern Oregon
   Current; 1981
   FS and BLM
   Bradley Smith, Forest Science Department, Oregon State University, Corvallis, OR 97331

5. Prescribed burning and vegetation response
   Current; 1982
   FS and Southern Oregon State College
   Sarah Greene, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97330

6. Vegetation-environment relationships in the Siskiyou Mountains
   Completed; 1963-69
   Oregon State University
   Richard Waring, Forest Science Department, Oregon State University, Corvallis, OR 97331

7. Vertebrates of Ashland RNA
   Completed; 1973
   Pacific Northwest Research Natural Area Committee
   Stephen P. Cross, Biology Department, Southern Oregon State College, Ashland, OR 97520

8. Wildlife utilization of riparian habitats in western Oregon
   Completed; 1979
   Southern Oregon State College and BLM
   Stephen P. Cross, Biology Department, Southern Oregon State College, Ashland, OR 97520

Atzet and Waring 1970 (6); Atzet and Wheeler 1984 (1, 4); Carroll and Carroll 1978 (3); Cross 1973 (7); Dennis 1959; Franklin and others 1972.

Bagby RNA, Mount Hood National Forest, OR (FS)

1. Amount and role of coarse woody debris in northwestern conifer forests
   Current; 1977
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
Completed; 1976-78
NSF and University of Oregon
George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Habitat type classification for western Cascade forests
Current; 1967
FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Vegetation classification of old-growth wildlife habitat
Current; 1983
FS
Tom Spies, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Carroll and Carroll 1978 (2); Franklin and Hemstrom 1981; Franklin and others 1981 (1, 3); Halvorsen and others 1985; Moi and others 1973b; Old-Growth Definition Task Group 1986 (4); Spies and others 1985 (4); Thomas and others 1979 (1).

Baird Basin RNA, Little Pend Oreille Wildlife Refuge, WA (FWS)

Franklin and others 1972.

Beatty Creek RNA, Roseburg District, OR (BLM)

1. Biosystematic studies of *Phacelia capitata* (Hydrophyllaceae), a species endemic to serpentine soils in southwestern Oregon
Completed; 1982-85
Oregon State University Herbarium and personal (J. Stephen Shelly)
J. Stephen Shelly, The Nature Conservancy, Helena, MT 5960

Shelly 1985.

Bills Creek Proposed RNA, Nez Perce National Forest, ID, administered by Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of grasslands
Current; 1983
FS
Charles Johnson, Wallowa-Whitman National Forest, Baker, O 97814

Blackwater Island RNA, Ridgefield Wildlife Refuge, WA (FWS)

1. Monitoring of plant communities after withdrawal of grazing
   Current; 1986
   FS, Washington State Department of Natural Resources, and Oregon State University
   Robert E. Frenkel, Geography Department, Oregon State University, Corvallis, OR 97331

Morrison 1973; Wiberg and Greene 1981.

Bluejay RNA, Winema National Forest, OR (FS)

1. Classification of ecosystems in the Mazama Pumice Region
   Completed; 1966-85
   FS
   Len Volland, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

Carroll and Carroll 1978 (2); Franklin and others 1972; Volland 1976 (1).

Boardman RNA, Department of the Navy, WA (DOD)[2]

1. Breeding chronology, habitat utilization, and nest-site selection of the long-billed curlew in north-central Oregon
   Completed; 1978-80
   Oregon State University and Northern Prairie Wildlife Research Center (FWS)
   Geoffrey Pampush, The Nature Conservancy, Portland, OR 97210

2. Bunchgrass (Agropyron spicatum) and cheatgrass (Bromus tectorum): study patches, genesis, dynamics, and status
   Current; 1982
   University of Oregon and The Nature Conservancy
   Alan Copsey, University of Oregon, Eugene, OR 97403

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[2] Boardman RNA is on the Boardman Bombing Range in eastern Oregon, but all correspondence should be directed to: Department of the Navy, Western Division, Naval Facilities Command, Building 138, Room 215, Naval Station, Seattle, WA 98115.

3. Effects of fire and grazing on Washington ground squirrels
Completed; 1982-84
Eastern Oregon State College and The Nature Conservancy
Burr J. Betts, Eastern Oregon State College, La Grande, OR 97850

4. Foraging ecology and habitat characteristics of the burrowing owl in the Columbia Basin, Oregon
Completed; 1980-83
FWS
Greg Green, Envirosphere Company, 10900 N.E. 8th, Bellevue,
WA 98004-4405

5. Geographic range, habitat requirements, and a preliminary population study of _Spermophilus_ _washingtoni_
Completed; 1978-80
NSF
Leif Carlson, Lewis and Clark College, Portland, OR 97219

6. Heptachlor contamination in eggs of hawks and owls
Completed; 1978-83
FWS
Charles Henny, U.S. Fish and Wildlife Service, 480 S.W. Airport Road, Corvallis, OR 97330

7. Shrub cover and shrub productivity
Completed; 1978-81
DOE
Colleen McShane, Battelle Inc., Richland, WA 99352

Carlson and others 1980 (5); Christy 1980; Green 1983 (4); Green and Anthony 1986 (4); Green and Morrison 1983 (4); Henny and others 1983 (6), 1984; Hoffnagle 1980; Janes 1983; Mayfield and Kjelmer 1984; Pampush 1981 (1).

Boner Flat Proposed RNA, Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of grasslands
Current; 1980
FS
Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Boston Glacier RNA, North Cascades National Park, WA (NPS)

Hubley 1956; LaChapelle 1962; Post and others 1971; Ringe 1973; Wiberg and McKee 1978.

Brewer Spruce RNA, Medford District, OR (BLM)

1. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

2. Ecological site classification of southwestern Oregon
   Current; 1981
   FS and BLM
   Bradley Smith, Forest Science Department, Oregon State University, Corvallis, OR 97331

3. Ecology of Port-Orford-cedar
   Current; 1974
   NSF and Oregon State University
   Don Zobel, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

Atzet and others 1984 (2); Atzet and Wheeler 1984 (2); Carroll and Carroll 1978 (1); Franklin and others 1972; Hawk 1977 (3); Waring 1969; Zobel 1979 (3), 1983 (3); Zobel and others 1985 (3).

Buckhorn Mountain Proposed RNA, Olympic National Forest, WA (FS)

1. Plant associations and habitat types of the Olympic National Forest
   Current; 1982
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Bull Run RNA, Mount Hood National Forest, OR (FS)

1. Community classification of the Silver Fir Zone
   Completed; 1979-82
   FS
   Nancy Halvorsen, Mount Hood National Forest, Gresham, OR 97030

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

Carroll and Carroll 1978; Franklin and others 1972; Hemstrom and others 1982 (1).

Butter Creek RNA, Mount Rainier National Park and Gifford Pinchot National Forest, WA (NPS and FS)

1. Avalanche communities and their environmental relationships
   Completed; 1976-81
   University of Washington
   Martha Cushman, Botany Department, University of Washington, Seattle, WA 98105

2. Classification of subalpine meadow communities in Washington Cascade Range
   Completed; 1968-73
   NPS and Oregon State University
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

3. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

4. Forest disturbance history of Mount Rainier National Park
   Completed; 1975-80
   NPS and FS
   Miles Hemstrom, Willamette National Forest, P.O. Box 10607, Eugene, OR 97440

5. Forest ecosystems of Mount Rainier National Park
   Completed; 1975-80
   NPS and FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

6. Relation of site index to habitat types in the Pacific Silver Fir Zone
   Current; 1967
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Bradley and Driver 1981; Cushman 1981 (1); Franklin and others 1971, 1972, 1986a (5); Hemstrom 1979a (4), 1979b (4); Hemstrom and Franklin 1982 (4); Henderson 1973 (2); Moir and others 1979a (5), 1979b (5).

The Butte RNA, Salem District, OR (BLM)

1. The Butte RNA monitoring program
   Current; 1984
   Salem District BLM Botany Project
   Larry R. Scofield, District Botanist, Bureau of Land Management, Salem, OR 97302

2. East and west slope effects on age structure and diameter of Pseudotsuga menziesii
   Completed; 1984-85
   Linfield College
   Richard Farris, Biology Department, Linfield College, McMinnville, OR 97128

Camas Swale RNA, Eugene District, OR (BLM)

1. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

2. Examination of small stand openings in a Douglas-fir forest in the Willamette Valley foothills (student research project)
   Completed; 1977
   University of Oregon
   Dick Vander Schaaf, The Nature Conservancy, 1234 N.W. 25th Street, Portland, OR 97210

3. Forest succession and aspects of microclimate on a south-facing slope in the BLM Camas Swale Research Natural Area (student research project)
   Completed; 1977
   University of Oregon
   Carl Johannessen, Geography Department, University of Oregon, Eugene, OR 97403

Carroll and Carroll 1978 (1); Curtis 1986a.

Canyon Creek RNA, Malheur National Forest, OR (FS)

1. Community classification of the Blue Mountain region
   Current; 1956
   FS
   Fred Hall, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

2. Distribution and role of conifer needle endophytes (fungi
 on needle surfaces)
 Completed; 1976-78
 NSF and University of Oregon
 George Carroll, Biology Department, University of Oregon,
 Eugene, OR 97403

3. Long-term photo analysis of vegetation change
 Current; 1956
 FS
 Fred Hall, USDA Forest Service, Pacific Northwest Region,
 319 S.W. Pine, Portland, OR 97208

Carroll and Carroll 1978 (2); Franklin and others 1972; Hall 1971 (1), 1973 (1), 1978 (1), 1979a, 1979b (1), 1980a, 1980b.

Carolyn's Crown RNA, Salem District, OR (BLM)

1. Carolyn's Crown RNA monitoring program
 Current; 1984
 Salem District BLM Botany Project
 Larry R. Scofield, District Botanist, Bureau of Land
 Management, Salem, OR 97302

2. Northern spotted owl designated management area (SOMA)
 monitoring study
 Current; 1984
 Salem District BLM Wildlife Project
 Wayne Logan, Wildlife Biologist, Bureau of Land Management, Salem, OR 97302

Cedar Flats RNA, Gifford Pinchot National Forest, WA (FS)

1. Classification of the Western Hemlock Zone
 Completed; 1982-86
 FS
 Nancy Halvorsen, Mount Hood National Forest, Gresham, OR
 97030

2. Distribution and role of conifer needle endophytes (fungi
 on needle surfaces)
 Completed; 1976-78
 NSF and University of Oregon
 George Carroll, Biology Department, University of Oregon,
 Eugene, OR 97403

3. Effect of mudflow deposits on soil development in Cedar Flats
Current; 1980
FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Long-term monitoring of posteruption channel adjustments and rates of erosion and deposition after eruption of Mount St. Helens
Current; 1980
U.S. Geological Survey
Holly Martinson, 5400 MacArthur Boulevard, Vancouver, WA 98660

5. Mammal and bird monitoring in old-growth wildlife habitats
Current; 1983
FS
S.D. West, College of Forest Resources, University of Washington, Seattle, WA 98105

6. Mortality after mudflow inundation
Current; 1980
FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

7. Snag and log decomposition study
Current; 1980
FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

8. Vegetation classification of old-growth wildlife habitat
Current; 1983
FS
Tom Spies, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

9. Vegetation recovery on terrace forest after mudflow inundation
Current; 1980
FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

10. Floristic inventory
    Completed; 1980-82
    Pacific Northwest Research Natural Area Committee
    Lynn C. Cornelius and Reid Schuller, Department of Natural Resources, Mail Stop EX-13, Olympia, WA 98504

Carroll and Carroll 1978 (2); Cornelius and Schuller 1982 (10); Franklin and others 1972; Frenzen and Franklin 1986 (9); Halpern and Harmon 1983 (9); Janda and others 1981; Murdorff 1984; Spies and others 1985 (8); Topik and others 1985 (1); U.S. Department of Agriculture, Forest Service 1981.

Cherry Creek RNA, Coos Bay District, OR (BLM)

1. Baseline water monitoring: flow, temperature, sediment
   Current; 1982
   BLM and Coos and Curry Counties
   Lloyd Fritz, Coos Bay District, Bureau of Land Management, Coos Bay, OR 97420

2. Composition and structure of old-growth forests in the Oregon Coast Range
   Completed; 1974-78
   Oregon State University and NPS
   Glenn Juday, Institute of Northern Forestry, Fairbanks, AK 99701

3. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

4. Vegetation classification of old-growth wildlife habitat
   Current; 1983
   FS
   Tom Spies, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Carroll and Carroll 1978 (3); Franklin and others 1972; Old-Growth Definition Task Group 1986 (4); Spies and others 1985 (4).

Chowder Ridge Proposed RNA, Mount Baker-Snoqualmie National Forest, WA (FS)

1. Bryophytes of Chowder Ridge
   Completed; 1983-85
   University of British Columbia and Western Washington University
   Ron Taylor, Western Washington University, Bellingham, WA 98225

2. Foraging preferences of alpine birds in relation to snow accumulation
   Completed; 1983-85
   Western Washington University
   Rod Norvell, 5809 Western View Place, Mount Airy, MD 21771

3. Genecological studies of *Cerastium arvense*
   Completed; 1983-85
   Western Washington University
   Ronald Taylor, Western Washington University, Bellingham, WA 98225

4. Lichens of Chowder Ridge
   Completed; 1984-85
   Arizona State University and Washington Native Plant Society
   Bruce Ryan, Arizona State University, Flagstaff, AZ 86011

5. Pollination ecology of an alpine fell-field community
   Completed; 1983-85
   Western Washington University and Washington Native Plant Society
   Ron Taylor, Western Washington University, Bellingham, WA 98225

Norvell 1985; Ryan 1985 (4); Shaw 1982 (5); Shaw and Taylor 1986 (5); Wagstaff 1986 (3).

Coquille River Falls RNA, Siskiyou National Forest, OR (FS)

1. Behavior of *Phytophthora* root rot
   Current; 1950
   Oregon State University
   Lewis Roth and Everett Hansen, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Ecology of Port-Orford-cedar
   Current; 1974
   NSF and Oregon State University
   Don Zobel, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

4. Habitat relationships between Port-Orford-cedar and western redcedar
   Completed; 1979-82
   Oregon State University and FS
   Don Zobel, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

5. Community types of the Siskiyou Mountain province
   Current; 1981
   FS
   Tom Atzet, Siskiyou National Forest, Grants Pass, OR 97526

Atzet and Wheeler 1984 (5); Carroll and Carroll 1978 (2); Franklin and others 1972; Hawk 1977 (3); Imper 1981 (3); Plocher 1977; Zobel 1979 (3), 1980 (3), 1983 (3).

Craig Mountain Lake Proposed RNA, Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of subalpine meadows
   Current; 1980
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Diamond Point RNA, Willapa National Wildlife Refuge, WA (FWS)

Franklin and others 1972.

Duck Lake Proposed RNA, Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of forest stands and aquatic communities
   Current; 1980
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

East Kiger Plateau RNA, Burns District, OR (BLM)

1. Checklist of vascular plants of Steens Mountain
   Current; 1972
   FWS and personal (Karl Urban)
   Karl Urban, Blue Mountain Community College, Pendleton, OR 97801

2. Vegetational differences between ungrazed and grazed Festuca communities on Steens Mountain
   Completed; 1984
   Malheur Field Station
   Lucille Housley, Executive Director, Malheur Field Station, Box 260-E, Princeton, OR 97221

Anonymous 1985.

Eldorado Creek Proposed RNA, Wenatchee National Forest, WA (FS)

1. Causes of avoidance and tolerance of native plants to serpentine soils
   Current; 1984
   National Aeronautics and Space Administration and University of Washington
   Sarah Cooke, Botany Department, University of Washington, Seattle, WA 98105

2. Evidence for ecotypic differentiation in Lupinus-associated Rhizobium
   Completed; 1979-82
   Dutch Government
   D.M. Pegtel, Vakgroep Plantenoecologie, Biologisch Centrum, Rijksuniversiteit Groningen, Postbus 14, 9750 AA Haren (Groningen), Netherlands

3. Hyperaccumulation of nickel by Arenaria rubella (Wahlenb.) J.E. Smith (Cartophyllaceae) from Washington State
   Completed; 1982
   University of Washington and NSF
   Art Kruckeberg, Botany Department, University of Washing ton, Seattle, WA 98105

4. Morphological responses (leaf morphologies) of serpentine tolerant races of edaphically indifferent species
   Current; 1984
   National Aeronautics and Space Administration and University of Washington
   Caren Cymerman, Botany Department, University of Washington, Seattle, WA 98105

del Moral 1972, 1974, 1982; Kruckeberg 1964, 1969a; Maas and Stuntz 1969; Main 1974; Pegtel 1980 (2).

Flynn Creek RNA, Siuslaw National Forest, OR (FS)

1. Alsea Basin logging and aquatic resources study[3]
   Completed; 1958-73
   Oregon State University, FS (Pacific Northwest Region), U.S. Geological Survey, U.S. Environmental Protection Agency, Georgia Pacific Corporation, Oregon Department of Fish and Wildlife, and Fred Williamson (land owner)
   Supervisor, Siuslaw National Forest, Corvallis, OR 97333

2. Caddisfly community of Flynn Creek
   Current; 1980
   Oregon State University
   Robert Wisseman, Entomology Department, Oregon State University, Corvallis, OR 97331

3. Decomposition and role of wood in stream ecosystems
   Current; 1978
   NSF and Oregon State University
   Kenneth Cummins, Appalachian Environmental Laboratory, University of Maryland, Frostburg, MD 21532

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[3] The Alsea Basin Logging and Aquatic Resources Study was a cooperative research program initiated by the Oregon Legislature to determine the impact of timber harvest and road construction on aquatic resources. The study was begun in 1958 and included the Alsea Basin Soil Survey and detailed research in three small experimental watersheds. The Flynn Creek watershed and subsequent RNA served as the control watershed. Cooperators in the study included Oregon State University, Pacific Northwest Region of the USDA Forest Service, U.S. Geological Survey, Environmental Protection Agency, Georgia Pacific Corporation, Oregon Department of Fish and Wildlife, and Fred Williamson, landowner.

4. Hydrology, sediment transport, channel morphology, and organic debris in Oregon coastal streams
Current; 1976
Oregon State University
Robert Beschta, Forest Engineering Department, Oregon State University, Corvallis, OR 97331

Adams and Beschta 1980 (4); Au 1972 (1); Beschta 1978 (1, 4), 1980 (4), 1981a (4), 1981b (4), 1983a (4), 1983b (4); Beschta and others 1981 (4); Brown 1967 (1, 4), 1969 (1, 4), 1970 (1, 4), 1972 (1, 4); Brown and Krygier 1967 (1, 4), 1970 (4), 1971 (1, 4); Brown and others 1973 (1, 4); Campbell 1970 (1); Campbell and others 1982 (4); Chapman 1961 (1), 1962 (1), 1965 (1), 1966 (1); Chapman and Demory 1963 (1); Chapman and others 1961 (1); Coble 1960 (1), 1961 (1); Corliss and Dyrness 1964 (1, 4), 1965 (1, 4); Demory 1961 (1); Gilleran 1968 (1); Hall 1968b (1); Hall and Campbell 1968 (1); Hall and Knight 1981 (1); Hall and Krygier 1967 (1); Hall and Lantz 1969 (1); Hansmann 1969 (1); Hansmann and others 1971 (1); Hansmann and Phinney 1973 (1); Harper 1969 (1, 4); Harr and Krygier 1972 (1, 4); Harr and others 1975 (1, 4); Harris 1972 (1, 4), 1973 (1, 4); Harris and Williams 1971 (1, 4); Hsieh 1970 (1, 4), 1975 (1, 4); Jackson 1981 (4); Knight 1980 (1); Koski 1966 (1); Krohn 1968 (1); Lantz 1967 (1), 1970 (1); Lindsay 1975 (1); Lowry 1964 (1), 1965 (1), 1966 (1); Moring 1975a (1, 4), 1975b (1); Moring and Lantz 1975 (1); O'Leary and Beschta 1981 (4); Phillips and Campbell 1962 (1); Phillips and others 1966 (1); Ringler 1970 (1); Ringler and Hall 1975 (1); Robinson and Wisseman 1983 (2); U.S. Department of the Interior, Geological Survey 1977 (1, 4); Vansickle and Beschta 1983 (4); Williams 1964 (1, 4); Wisseman and Anderson 1984 (2), in press (2).

Fox Hollow RNA, Eugene District, OR (BLM)

1. Ecosystem dynamics in the coniferous forest of the Willamette Valley, Oregon, USA
Completed; Unknown-1977
University of Oregon
Carl Johannessen, Geography Department, University of Oregon, Eugene, OR 97403

Cole 1977 (1); Curtis 1986b.

Goat Marsh RNA, Gifford Pinchot National Forest, WA (FS)

1. Composition, structure, and distribution of subalpine forests in the Washington Cascades
Completed; 1962-76
FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

2. Flora of the Goat Marsh Research Natural Area
   Completed; 1980-82
   Pacific Northwest Natural Area Committee
   Reid Schuller, Department of Natural Resources, Mail Stop EX-13, Olympia, WA 98504

3. Productivity analysis of a superlative noble fir stand
   Current; 1976
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Relation of site index to habitat types in the Pacific Silver Fir Zone
   Current; 1967
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Brockway and others 1983; Franklin 1966 (1), 1983 (3); Franklin and Wiberg 1979; Fujimori and others 1976 (3); Mullineaux and Crandell 1962; Ruetz 1981; Schuller and Cornelius 1982 (2).

Gold Lake Bog RNA, Willamette National Forest, OR (FS)

1. Bog communities and flora in the Cascade Range
   Current; 1976-79
   NPS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

2. Hybridization of Gold Lake Bog populations of *Rana cascadae* and *R. pretiosa*
   Completed; 1984
   McMaster University
   David Green, Biology Department, McMaster University, Hamilton, Ontario, Canada L8S 4K1

Baugh 1975; Christy 1980; Christy and others 1982; Franklin and others 1972; Hemstrom and others 1982, 1985; Kezer 1978; Klopsch and others 1979; Seyer 1979 (1).

Goodlow Mountain RNA, Fremont National Forest, OR (FS)

1. Bark beetle activity investigation, 1922-40
   Completed; 1922-40
   FS and Bureau of Entomology and Plant Quarantine
   Sarah E. Greene, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Growth and yield studies--four permanent plots
   Completed; 1975-80
   FS
   William Hopkins, Silviculture Laboratory, Bend, OR 99701

4. Photo sampling of plant succession after fire
   Current; 1979
   FS
   William Hopkins, Silviculture Laboratory, Bend, OR 99701

Carroll and Carroll 1978 (2); Franklin and others 1972; Hopkins 1979 (3, 4).

Government Draw Proposed RNA, Wallowa-Whitman National Forest, OR (FS)

1. Permanent photo points to follow vegetation change
   Current; 1956
   FS
   Fred Hall, Ecologist, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

Grass Mountain RNA, Salem District, OR (BLM)

1. Grass Mountain RNA monitoring program
   Current; 1984
   Salem District BLM Botany Project
   Larry R. Scofield, District Botanist, Bureau of Land Management, Salem, OR 97302

Green Mountain Proposed RNA, Mount Baker-Snoqualmie National Forest, WA (FS)

1. Plant associations and habitat types of the Mount Baker-Snoqualmie National Forest
   Current; 1983
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Hades Creek RNA, Olympic National Park, WA (NPS)

Buckhorn and Orr 1959; Crandell 1964; Danner 1955; Franklin and others 1972; Pomeroy and Dixon 1966.

Hagan Proposed RNA, Willamette National Forest, OR (FS)

1. Aquatic habitat utilization by salmonoids
   Current; 1976
   Oregon State University and NSF
   Jim Hall, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331

2. Aquatic primary production
   Current; 1981
   Oregon State University and NSF
   Stan Gregory, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331

3. Channel changes and geomorphic processes
   Current; 1981
   FS
   Fred Swanson, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Comparison of small mammal use in upland riparian habitats
   Completed; 1982-84
   Oregon State University and NSF
   Arlene Doyle, Redwood Sciences Laboratory, Arcata, CA 95521

5. Distribution of Phellinus patches by habitat type
   Completed; 1978-79
   FS
   Don Knutson, 143 Bedford St. S.E., P.O. Box 14666, Minneapolis, MN 55414

6. Dynamics of riparian vegetation
   Current; 1982
   Oregon State University, NSF, and FS
   Art McKee, Forest Science Department, Oregon State University, Corvallis, OR 97331

7. Fish population dynamics
   Current; 1981
   Oregon State University and NSF
   Stan Gregory, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331

8. Importance of fire history on the stand structure of Douglas-fir forests in the Pacific Northwest
   Completed; 1977-85
   Oregon State University
   Mark Klopsch, Forest Science Department, Oregon State University, Corvallis, OR 97331

9. Long-term successional dynamics of upland forests
Current; 1981
NSF and FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

10. Microbial processes and dynamics of dissolved organic materials in streams
Current; 1981
Oregon State University and NSF
Stan Gregory, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331

11. Microclimate of forest stands
Current; 1977
NSF and FS
Art McKee, Forest Science Department, Oregon State University, Corvallis, OR 97331

12. Old-growth wildlife habitat relationships--research and development: animals, birds, herpes
Completed; 1983-85
FS
Len Ruggiero, Forestry Sciences Laboratory, 3625 93rd Avenue S.W., Olympia, WA 98502

13. Retention of allocthanous input
Current; 1981
Oregon State University and NSF
Stan Gregory, Fisheries Department, Oregon State University, Corvallis, OR 97331

14. Seasonal dynamics of aquatic invertebrates
Current; 1981
Oregon State University and NSF
Norm Anderson, Entomology Department, Oregon State University, Corvallis, OR 97331

15. Sediment routing in disturbed and undisturbed watersheds
Current; 1981
Oregon State University, NSF, and FS
Fred Swanson, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

16. Upland versus riparian productivity
    Current; 1981
    Oregon State University and FS
    Art McKee, Forest Science Department, Oregon State University, Corvallis, OR 97331

Campbell and Franklin 1979; Franklin and others 1986b, in press; Grant and others 1984; Gregory 1983; Klopsch 1985; Klopsch and others 1979; McKee and others 1978, 1981, 1982; Old-Growth Definition Task Group 1986 (12); Spies and others 1985 (12); Swanson 1981; Swanson and others 1982; Waring 1982; Waring and Franklin 1979.

Harney Lake RNA, Malheur National Wildlife Refuge, OR (FWS)

1. Factors affecting the ecology of small mammals on the Malheur National Wildlife Refuge
    Completed; 1973-77
    Oregon State University
    George A. Feldhamer, c/o Zoology Department, Oregon State University, Corvallis, OR 97331

2. Snowy plover survey
    Completed; 1980-81
    FWS
    Steve Herman, The Evergreen College, Olympia, WA 98505

Copeland 1979; Cornely 1980; Feldhamer 1977 (1); Herman and others 1981 (2); Malheur National Wildlife Refuge 1980; Piper and others 1939; Walker and Swanson 1968a.

Higley Creek RNA, Olympic National Park, WA (NPS)

Crandell 1964; Danner 1955; Franklin and others 1972; Kirk 1966; Sharpe 1956.

High Peak-Moon Creek RNA, Salem District, OR (BLM)

1. High Peak-Moon Creek RNA monitoring program
    Current; 1984
    Salem District BLM Botany Project
    Larry R. Scofield, District Botanist, Bureau of Land Management, Salem, OR 97302

2. Monitoring study on Scoliopus hallii to determine biological requirements for the species and as a key indicator species to monitor riparian and wet area plant community structure
   Current; 1985
   Salem District BLM Botany Project
   Larry R. Scofield, District Botanist, Bureau of Land Management, Salem, OR 97302

Hoover Gulch Proposed RNA, Siskiyou National Forest, OR (FS)

1. Plant community and vegetation mapping of central Siskiyou Mountains
   Completed; 1982-84
   National Aeronautics and Space Administration
   Robert E. Frenkel, Geography Department, Oregon State University, Corvallis, OR 97331

Frenkel and Kiilsgaard 1984 (1).

Horse Ridge RNA, Prineville District, OR (BLM)

1. Baseline studies of bird and mammal populations
   Completed; 1967-77
   FWS
   Jay Gashwiler, c/o Silviculture Laboratory, Bend, OR 99701

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Relation of net primary productivity, leaf area, and biomass to vegetation zones in the Pacific Northwest
   Completed; 1976-79
   Oregon State University
   Henry Gholz, School of Forest Resources, University of Florida, Gainesville, FL 32611

4. Canopy modeling and leaf chemistry
   Current; 1985
   National Aeronautics and Space Administration
   Nancy Swanberg, Mail Stop 242, Moffett Field, CA 94035

5. Leaf area and spectral relationships
   Completed; 1983-84
   National Aeronautics and Space Administration
   Mike Spanner and Dave Peterson, Mail Stop 242, Moffett Field, CA 94035

6. Evaluating bidirectional canopy reflectance model
   Current; 1986
   National Aeronautics and Space Administration
   Allan Strahler, Geology and Geography Department, Hunter College, New York, NY 10021

Carroll and Carroll 1978; Franklin and others 1972; Gashwiler 1977 (1); Gholz 1979, 1980, 1982 (3); Spanner and others 1984 (5).

Hot Lakes RNA, Spokane District, WA (BLM)

Broch 1969.

Indian Creek RNA, Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of forest stands
   Current; 1985
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Greene 1983.

The Island RNA, Prineville District, OR (BLM) and Ochoco National Forest, OR (FS)

Driscoll 1964.

Jackson Creek RNA, Olympic National Park, WA (NPS)

1. Community ecology of the Olympic Rain Forest
   Completed; 1970-74
   NSF
   Richard Fonda, Biology Department, Western Washington University, Bellingham, WA 98225

2. Ecology of the Roosevelt elk
   Current; 1976
   NPS
   Ed Starkey, National Park Service, Cooperative Park Studies Unit, College of Forestry, Oregon State University, Corvallis, OR 97331

3. Forest types of Olympic National Park
   Current; 1978
   NPS
   Bradley Smith, Forest Science Department, Oregon State University, Corvallis, OR 97331

Crandell 1964; Danner 1955; Franklin and others 1972; Henderson and others 1978; Jenkins 1979 (2), 1981 (2); Jenkins and Starkey 1980a (2), 1980b (2), 1982 (2); Kirk 1966; Leslie 1982 (2); Smith and Henderson 1986 (3).

Jordan Craters RNA, Vale District, OR (BLM)

1. Birds and mammals of sagebrush steppe in Oregon
   Completed; 1979-86
   BLM
   Chris Maser, Bureau of Land Management, 3200 Jefferson Way, Corvallis, OR 97331

2. Core sampling of lake sediments--Upper Cow Lake
   Current; 1986
   Washington State University
   Peter J. Mehringer, Jr., Washington State University, Pullman, WA 99163

3. Effect of beaver utilization on red willow in southeastern Oregon
   Completed; 1978-84
   BLM
   Robert Kindschy, Bureau of Land Management, P.O. Box 700, Vale, OR 97918

4. Geologic and minerals resources inventory of the Jordan Craters, Jackie Butte, and Saddle Butte volcanic fields, Malheur County, OR
   Completed; 1979
   BLM
   John W. Harbaugh, 609 Mission Street, Suite 400, San Francisco, CA 94105

5. Petrography of the basalts of the Cow Creek Lakes area, Malheur County, OR
   Completed; 1963-65
   University of Oregon
   Geology Department, University of Oregon, Eugene, OR 97403

Glad 1974; Harbaugh and Lambie 1979 (4); Hart 1983; Heady and Bartolome 1977; Kindschy 1960-77, 1985; Kindschy and Maser 1978; Maser 1974-76 (1); Millhollen 1965 (5); Newcomb 1962; Otto and Hutchison 1977; Packard 1976.

Lake Twenty-Two RNA, Mount Baker-Snoqualmie National Forest, WA (FS)

1. Plant associations and habitat types of the Mount Baker-Snoqualmie National Forest
   Current; 1983
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Franklin and others 1972; Wolcott 1961.

Lightning Creek Proposed RNA, Nez Perce National Forest, ID, administered by Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of forest stands and grasslands
   Current; 1982
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Lily Lake Proposed RNA, Mount Baker-Snoqualmie National Forest, WA (FS)

1. Plant associations and habitat types of the Mount Baker-Snoqualmie National Forest
   Current; 1980
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Limpy Rock RNA, Umpqua National Forest, OR (FS)

1. Preliminary analysis of soil variability within specific landscape element and vegetation habitats in selected forests of western Oregon
   Completed; 1981-82
   Oregon State University
   D.J. Herbert Huddleston, Soils Department, Oregon State University, Corvallis, OR 97331

2. Relation of crown characteristics to remote sensing imagery characteristics
   Completed; 1983
   Oregon State University
   Bill Ripple, Environmental Remote Sensing Applications Laboratory, Oregon State University, Corvallis, OR 97331

3. Synecology of the Monotropideae
   Completed (monitoring continuing); 1982-86
   Oregon State University and FS
   Dan Luoma, Geography Department, Oregon State University, Corvallis, OR 97331

Luoma 1986 (3); Myhrum 1983.

Little Blitzen RNA, Burns District, OR (BLM)

1. Checklist of vascular plants of Steens Mountain
   Current; 1972
   FWS and personal (Karl Urban)
   Karl Urban, Blue Mountain Community College, Pendleton, OR 97801

2. Sensitive plants of Steens Mountain
   Current; 1972
   Personal (Karl Urban)
   FWS and Karl Urban, Blue Mountain Community College, Pendleton, OR 97801

Little Cultus Lake Proposed RNA, Deschutes National Forest, OR (FS)

1. National surface water survey (for acid rain research)
   Completed; 1985
   FS
   Rick Ross, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

Little Granite Proposed RNA, Nez Perce National Forest, ID, administered by Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of forest stands and grasslands
   Current; 1983
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Little Sink RNA, Salem District, OR (BLM)

1. Composition and structure of old-growth forests in the Oregon Coast Range
   Completed; 1974-78
   Oregon State University and NPS
   Glenn Juday, Institute of Northern Forestry, Fairbanks, AK 99701

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Floral and faunal studies of Willamette foothill forests and ponds
   Current; 1973
   Personal (Morris Johnson)
   Morris Johnson, Biology Department, Western Oregon State College, Monmouth, OR 97361

4. Little Sink RNA monitoring program
   Current; 1984
   Salem District BLM Botany Project
   Larry R. Scofield, District Botanist, Bureau of Land Management, Salem, OR 97302

5. Population genetics of _Ambystoma_ _gracile_
   Current; 1985
   NSF
   Tommy Titus, Zoology Department, University of Kansas, Lawrence, KS 66044

Carroll and Carroll 1978 (2); Hawk 1974; Juday 1976 (1).

Little Wildhorse RNA, Burns District, OR (BLM)

1. Checklist of vascular plants of Steens Mountain
   Current; 1972
   FWS and personal (Karl Urban)
   Karl Urban, Blue Mountain Community College, Pendleton, OR 97801

Long Creek RNA, Mount Baker-Snoqualmie National Forest, WA (FS)

1. Plant associations and habitat types for the Mount Baker-Snoqualmie National Forest
   Current; 1983
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Franklin and others 1972.

Long Draw RNA, Burns District, OR (BLM)

1. Floristic inventory
   Current; 1986
   Native Plant Society of Oregon
   Peter Zika and Lois Kemp, 1960 N.W. Lovejoy, #2, Portland, OR 97209

Lost Forest RNA, Lakeview District, OR (BLM)

1. Characteristics and causes of disjunct ponderosa pine forest
   Completed; 1960-63
   Oregon State University
   D.W. Berry, Northern Arizona University, Flagstaff, AZ 86011

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

Allison 1954; Antevs 1938, 1955; Berry 1963 (1); Carroll and Carroll 1978 (2); Dole 1942; Hansen 1947; Howard 1946; Keen 1937; Moir and others 1973a; Morrison 1965; Waring 1908.

Maitlen Creek RNA, Colville National Forest, WA (FS)

Williams and Lillybridge 1985.

Maple Knoll RNA, William L. Finley National Wildlife Refuge, OR (FWS)

1. Bird communities in Willamette Valley forests
   Completed; 1967-72
   Oregon State University
   Refuge Manager, Finley National Wildlife Refuge, Corvallis, OR 97331

Anderson 1970a, 1970b; Franklin and others 1972.

Maple Mountain Proposed RNA, Okanogan National Forest, WA (FS)

1. Community types and long-term vegetation permanent sample plot of the Okanogan National Forest
   Current; 1980
   FS
   Clint Williams, Okanogan National Forest, Okanogan, WA 98840

Williams and Lillybridge 1983 (1).

Meeks Table RNA, Wenatchee National Forest, WA (FS)

1. Botanical reconnaissance of Meeks Table
   Completed; 1983-86
   FS
   Reid Schuller, Department of Natural Resources, Mail Stop EX-13, Olympia, WA 98504

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Energy and nutrient budgets in east-side forests
   Completed; 1973
   NSF, University of Washington, and FS
   Charles Grier, College of Forest Resources, University of Washington, Seattle, WA 98105

4. Community types and long-term vegetation permanent sample plots of the Wenatchee National Forest
   Current; 1977
   FS
   Clint Williams, Okanogan National Forest, Okanogan, WA 98840

5. Plant communities and soils of Meeks Table
   Completed; 1970-77
   FS
   Arthur R. Tiedemann, Forestry and Range Sciences Laboratory, Box 2315, La Grande, OR 97850

Carroll and Carroll 1978 (2); Franklin and others 1972; Schuller and Evans 1986 (1); Tiedemann and Klock 1977 (5).

Metolius RNA, Deschutes National Forest, OR (FS)

1. Classification of ecosystems in the Mazama pumice region
   Completed; 1973-85
   FS
   Len Volland, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Forest ecosystem parameters that influence remotely sensed spectral characteristics
   Current; 1982
   National Aeronautics and Space Administration
   Chris Kiilsgaard, Geography Department, Oregon State University, Corvallis, OR 97331

4. Growth, yield, and mortality of old-growth ponderosa pine
   Current; 1981
   FS
   Sarah Greene, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

5. Quantitative study of normal snag conditions
   Current; 1979
   FS
   Bill Hopkins, Silviculture Laboratory, Bend, OR 99701

6. Relation of net primary productivity, leaf area, and biomass to vegetation zones in the Pacific Northwest
   Completed; 1976-79
   Oregon State University
   Henry Gholz, School of Forest Resources, University of Florida, Gainesville, FL 32611

7. Canopy modeling and leaf chemistry
   Current; 1985
   National Aeronautics and Space Administration
   Nancy Swanberg, Mail Stop 242, Moffett Field, CA 94035

8. Leaf area and spectral relationships
   Completed; 1983-84
   National Aeronautics and Space Administration
   Mike Spanner and Dave Peterson, Mail Stop 242, Moffett Field, CA 94035

9. Evaluating bidirectional canopy reflectance model
   Current; 1986
   National Aeronautics and Space Administration
   Allan Strahler, Geology and Geography Department, Hunter College, New York, NY 10021

Carroll and Carroll 1978 (2); Franklin and others 1972; Gholz 1979 (6), 1982 (6); Scott 1977; Spanner and others 1984 (8); Swedberg 1961, 1973; Volland 1976 (1).

Middle Santiam RNA, Willamette National Forest, OR (FS)

1. Growth, yield, and mortality of an old-growth Douglas-fir--western hemlock community
   Current; 1977
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

2. Mapping and monitoring of an active earthflow
   Current; 1979
   FS
   Fred Swanson, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

3. Riparian community classification
   Completed; 1973-79
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Vegetation classification of old-growth wildlife habitat
   Current; 1983
   FS
   Tom Spies, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Campbell and Franklin 1979 (3); Fujimori and others 1976; Greene and Franklin in press; Hicks 1982 (2); Klopsch and others 1979; Old-Growth Definition Task Group 1986 (4); Spies and others 1985 (4); Waring and Franklin 1979.

Mill Creek RNA, Mount Hood National Forest, OR (FS)

1. Classification of the Grand Fir and Ponderosa Pine Zones
   Current; 1982
   FS
   Nancy Halvorsen, Mount Hood National Forest, Gresham, OR 97030

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

Carroll and Carroll 1978 (2); Franklin and others 1972.

Mohawk RNA, Eugene District, OR (BLM)

1. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George C. Carroll and F.E. Carroll, Biology Department, University of Oregon, Eugene, OR 97403

Carroll and Carroll 1978 (1); Curtis 1986c.

Myrtle Island RNA, Roseburg District, OR (BLM)

1. Flora and communities of Myrtle Island
   Completed; 1970-79
   Private
   Ralph Thompson, Berea College, Berea, KY 40404

Franklin and others 1972; Thompson 1979 (1).

Neskowin Crest RNA, Siuslaw National Forest, OR (FS)

1. Composition and structure of old-growth forests in the Oregon Coast Range
   Completed; 1974-78
   Oregon State University and NPS
   Glenn Juday, Institute of Northern Forestry, Fairbanks, AK 99701

2. Contribution rates and physical characteristics of large organic debris in Oregon Coast Range streams under second-growth forests
   Current; 1985
   Oregon State University
   David Heiman, Forest Engineering Department, Oregon State University, Corvallis, OR 97331

3. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Corvallis, OR 97331

4. Ecological monitoring of long-term effects of energy development
   Completed; 1980-84
   DOE
   W.T. Hinds, Battelle Memorial Institute, Pacific Northwest Lab, Richland, WA 99352

5. Growth, mortality, and succession in a coastal spruce-hemlock forest
   Current; 1978
   FS
   Sarah Greene, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

6. Logs as sites of tree regeneration
   Current; 1981-86
   NPS
   Mark Harmon, Forest Science Department, Oregon State University, Corvallis, OR 97331

7. Mammals of the Oregon coast
   Completed; 1970-81
   University of Puget Sound and private
   Chris Maser, Bureau of Land Management, 3200 Jefferson Way, Corvallis, OR 97331

8. Reproductive ecology of conifers in the Sitka Spruce Zone
   Current; 1978
   FS and University of Alberta
   George LaRoi, Botany Department, University of Alberta, Edmonton, Alberta, Canada T6G 2E9

9. Vegetation of a coastal headland prairie
   Completed; 1964-67
   Oregon State University
   William Chilcote, retired, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

Carroll and Carroll 1978 (3); Christy 1980; Davidson 1967 (9); Franklin and others 1986b (5); Greene 1982, 1984 (5); Harmon 1986 (6); Hemstrom and Logan 1986; Hinds 1984 (4); Juday 1976 (1); Madison 1957; Maser and others 1981 (7); McShane and others 1983 (4); Quay 1982; Ripley 1983.

North Fork Nooksack RNA, Mount Baker-Snoqualmie National Forest, WA (FS)

1. Characteristics of litter layers in northwestern forests
   Completed; 1960-65
   University of Washington
   Stanley P. Gessel, College of Forest Resources, University of Washington, Seattle, WA 98105

2. Flora, community types, and soils of North Fork Nooksack RNA
   Completed; 1978-81
   FS
   Western Washington University
   Richard Fonda, Biology Department, Western Washington University, Bellingham, WA 98225

3. Relationship between snowmelt and vegetation pattern
   Current; 1984
   Western Washington University
   Ray Evans, Botany Department, Western Washington University, Bellingham, WA 98225

4. Physiological response of red heather (*Phyllodoce empetriformis*) to drought
   Current; 1986
   Western Washington University
   Elizabeth Binney, Botany Department, Western Washington University, Bellingham, WA 98225

5. Plant associations and habitat types of the Mount Baker-Snoqualmie National Forest
   Current; 1984
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Evans 1986 (3); Fonda 1981 (2); Franklin and others 1972; Gessel and Balci 1965 (1); Misch 1952; Thomas and others 1981.

North Myrtle Creek RNA, Roseburg District, OR (BLM)

1. Ecological site classification of southwestern Oregon
   Current; 1981
   FS
   Bradley Smith, Forest Science Department, Oregon State University, Corvallis, OR 97331

Ochoco Divide RNA, Ochoco National Forest, OR (FS)

1. Classification of the forests of the Blue Mountain region
   Completed; 1956
   FS
   Fred Hall, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Ecological monitoring of long-term effects of energy development
   Completed; 1980-82
   DOE
   W.T. Hinds, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, WA 99352

4. Long-term photo analysis of vegetation change
   Current; 1956
   FS
   Fred Hall, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

5. Reintroduction of natural fire cycle
   Current; 1984
   FS
   Sarah Greene and Bill Hopkins, Silviculture Laboratory, Bend, OR 99701

Carroll and Carroll 1978 (2); Franklin and others 1972; Hall 1967, 1971 (1), 1973, 1978, 1979a (1, 5), 1979b, 1980a, 1980b; Hinds 1984 (3).

Olallie Ridge RNA, Willamette National Forest, OR (FS)

1. Disjunct flora of the western Cascade peaks
   Completed; 1963-68
   University of Oregon
   James Hickman, Botany Department, University of California-Berkeley, Berkeley, CA 94720

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Habitat type classification for western Cascade forests
   Current; 1967-76
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Carroll and Carroll 1978 (2); Franklin and Mitchell 1967; Franklin and others 1972; Hemstrom and others 1982 (3), 1985 (3); Hickman 1968 (1), 1976 (1); Klopsch and others 1979.

Pataha Bunchgrass RNA, Umatilla National Forest, WA (FS)

1. Classification of the forests of the Blue Mountain region
   Current; 1956
   FS
   Fred Hall, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

2. Long-term photo analysis of vegetative change
   Current; 1956
   FS
   Fred Hall, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

Franklin and others 1972; Hall 1968a (1), 1970 (1), 1973 (1), 1980a (1).

Perry Creek Proposed RNA, Mount Baker-Snoqualmie National Forest, WA (FS)

1. Plant associations and habitat types of the Mount Baker-Snoqualmie National Forest
   Current; 1982
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Pigeon Butte RNA, William L. Finley National Wildlife Refuge, OR (FWS)

1. Bird communities in Willamette Valley forests
   Completed; 1967-72
   Oregon State University
   Refuge Manager, Finley National Wildlife Refuge, Corvallis, OR 97331

2. Forest productivity along environmental gradients
   Completed; 1972-73
   Japanese Forest Experiment Station
   Takao Fujimori, c/o Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

3. Effects of environment on decomposition and nutrient-cycling processes
   Completed; 1974-76
   NSF
   Oregon State University
   Kermit Cromack, Forest Science Department, Oregon State University, Corvallis, OR 97331

Anderson 1970a (1), 1970b (1), 1972 (1); Bickford 1979; Franklin and others 1972; Thilenius 1964, 1968.

Pine Creek RNA, Turnbull National Wildlife Refuge, WA (FWS)

1. Ecology of snail, *Lymnaea stagnalis*
   Current; 1967
   Eastern Washington University
   Bruce Lang, Biology Department, Eastern Washington University, Cheney, WA 99004

2. Epiphytic lichens on ponderosa pine
   Completed; 1972-75
   Eastern Washington University
   Horace Sims, Biology Department, Eastern Washington University, Cheney, WA 99004

3. Flora of Turnbull National Wildlife Refuge
   Current; 1975
   Eastern Washington University
   Ken Swedberg, Biology Department, Eastern Washington University, Cheney, WA 99004

4. Myxomycetes on ponderosa pine logs
   Completed; 1969-70
   Eastern Washington University
   Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

Bretz 1959; Donaldson and Giese 1968; Franklin and others 1972; Lang 1977 (1); Stevens 1975 (2); Zabel 1970 (4).

Pleasant Valley Proposed RNA, Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of grasslands and forest stands
   Current; 1980
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

2. Study of vegetation and grazing with three-way exclosures
   Current; 1964
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Poker Jim Ridge RNA, Hart Mountain National Wildlife Refuge, OR (FWS)

Greene and Copeland 1984; Larson 1965; Walker and Swanson 1968b.

Port-Orford-Cedar RNA, Siskiyou National Forest, OR (FS)

1. Behavior of Phytophthora root rot
   Current; 1950
   Oregon State University
   Lewis Roth and Everett Hansen, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

2. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

3. Ecology of Port-Orford-cedar
   Current; 1974
   NSF
   Oregon State University
   Don Zobel, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

4. Habitat relationships between Port-Orford-cedar and western redcedar
   Current; 1979-82
   Oregon State University and FS
   Don Zobel, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331

5. Community types of the Siskiyou Mountains Province
   Current; 1981
   FS
   Tom Atzet, Siskiyou National Forest, Grants Pass, OR 97526

Atzet and Wheeler 1984 (5); Carroll and Carroll 1978 (2); Franklin and others 1972; Hawk 1977 (3, 4); Imper 1981 (3, 4); Lawson 1983; Zobel 1980 (3, 4).

Pringle Falls RNA, Deschutes National Forest, OR (FS)

1. Age structure and spatial pattern of old-growth ponderosa pine
   Completed; 1981-85
   FS
   Joseph Means, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

2. Baseline studies of bird and mammal populations
   Completed; 1967-77
   FWS
   Jay Gashwiler, c/o Silviculture Laboratory, Bend, OR 99701

3. Classification of ecosystems in the Mazama pumice region
   Completed; 1971-85
   FS
   Len Volland, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

4. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

5. Effects of environment on decomposition and nutrient-cycling processes
   Completed; 1974-76
   NSF and Oregon State University
   Kermit Cromack, Forest Science Department, Oregon State University, Corvallis, OR 97331

6. Growth of ponderosa and lodgepole pine forests
   Completed; 1960-70
   FS
   Jim Barrett, 61555 Ward Road, Bend, OR 99701

7. Seed production by ponderosa and lodgepole pines
   Completed; 1953-75
   FS
   Walt Dahm and Jim Barrett, 61555 Ward Road, Bend, OR 99701

8. Reintroduction of "natural" fire
   Current; 1985
   FS
   Ken Seidel, Silviculture Laboratory, 1027 N.W. Trenton Avenue, Bend, OR 97701

Bork 1985 (8); Carroll and Carroll 1978 (4); Dahms and Barrett 1975 (7); Franklin and others 1972; Gashwiler 1977 (2); Morrow 1985 (1); Mowat 1954; Tarrant 1947; U.S. Department of Agriculture, Forest Service 1938; Volland 1976 (3).

Pyramid Lake RNA, North Cascades National Park, WA (NPS)

1. Collections of Hepaticae, genus Porella
   Completed; 1981
   College of Great Falls, MT
   Won Shic Hong, College of Great Falls, Great Falls, MT 59405

2. Monitoring water quality, chemistry, and aquatic life of Pyramid Lake RNA
   Current; 1971
   NPS
   Robert Wasem, North Cascades National Park, Sedro Woolley, WA 98284

Zobel and Wasem 1979.

Quinault RNA, Olympic National Forest, WA (FS)

1. Ecological monitoring of long-term effects of energy development
   Completed; 1980-84
   DOE
   W.T. Hinds, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, WA 99352

2. Effects of acid rain on nitrogen fixation in western Washington coniferous forests
   Completed; 1974
   NSF
   Oscar Soule, The Evergreen College, Olympia, WA 98505

3. Growth and yield of Sitka spruce-western hemlock stands
   Current; 1982
   FS
   Sarah Greene, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Logs as sites of tree regeneration
   Completed; 1981-86
   NPS
   Mark Harmon, Forest Science Department, Oregon State University, Corvallis, OR 97331

5. Plant associations and habitat types of the Olympic National Forest
   Current; 1980
   FS
   Jan Henderson, Olympic National Forest, Olympia, WA 98507

Crandell 1964; Danner 1955; Denison 1977 (2); Denison and others 1976 (2); Franklin and others 1972; Henderson and Peter 1981 (5); Hinds 1984 (1); Hinds and others 1981 (1); McShane and others 1983 (1); Shelford 1963; Skalski and others 1981 (1); Thomas and others 1981 (1).

Rainbow Creek RNA, Umatilla National Forest, WA (FS)

1. Classification of the forests of the Blue Mountain region
   Current; 1956
   FS
   Fred Hall, USDA Forest Service, Pacific Northwest Region, 319 S.W. Pine, Portland, OR 97208

2. Tree and stand growth after defoliation by Douglas-fir tussock moth
   Current; 1973
   FS
   Boyd Wickman, Forestry and Range Sciences Laboratory, La Grande, OR 97850

Franklin and others 1972; Hall 1973 (1), 1978 (1), 1979b (1), 1980b; Wickman 1978 (2); Wickman and others 1980 (2).

Rattlesnake Hills RNA, Arid Lands Ecology (ALE) Reserve, WA (DOE)

1. Arid land ecology[4/]
   Current; 1965
   DOE
   L.E. Rogers, Battelle, Pacific Northwest Laboratory, P.O. Box 999, Richland, WA 99352

2. National Environmental Research Park[5/]
   Current; 1977
   DOE
   W.H. Rickard, Battelle, Pacific Northwest Laboratory, P.O. Box 999, Richland, WA 99352

3. University-supported ecological studies[6/]
   Current; 1980
   NSF and Washington State University
   R.N. Mack, A.A. Black, Jeff Johansen, William Rayburn, Washington State University, Pullman, WA 99164-2930

[4/] Studies include primary and secondary productivity, mineral cycling, and water balance. Funding is provided by the U.S. Department of Energy, Office of Health and Environmental Research, Ecological Research Division, Washington, DC.

[5/] Studies in this category are provided logistic support by the U.S. Department of Energy, Office of Health and Environmental Research, Ecological Research Division, Washington, DC, for student research leading to graduate degrees. Stipends are provided through the Tri Cities University Center, c/o Dr. Bryan Valett, Director, Northwest Organization of Colleges and Universities for Science, 100 Sprout Road, Richland, WA 99352. Ongoing student research includes radiotelemetry studies of free-roaming elk and coyotes and ecological studies of two lupine populations.

[6/] Ongoing studies in this category include ecological genetics of cheatgrass, response of soil algae to wildfire, and response of shrub-steppe plants to Mount St. Helens ash fall. Funding is provided for ongoing studies by the National Science Foundation and Washington State University.

Allen 1980 (2); Cline and others 1977a (1), 1977b (1); Cline and Rickard 1973 (1), 1974 (1); Fitzner 1978a (2), 1978b (2); Fitzner and others 1978 (1); Franklin and others 1972 (3); Gano and Rickard 1982 (3); Hajek 1966 (1); Hajek and Wildung 1969 (1); Hakonson and Rickard 1969 (1); Harr and Price 1972 (1); Hedlund and Rickard 1981 (1); Hinds 1973 (1), 1974 (1), 1975 (1), 1979 (1); Hinds and others 1979 (1); Hinds and Rickard 1968 (1), 1973 (1); Hinds and Rotenberry 1979 (1); Hinds and Thorp 1969 (1); Johnson 1974 (2); Kritzman 1970 (3); Langham 1970 (2); Mack 1971 (2); Mack and Pyke 1984 (3); McCorquodale 1985 (1); McCullough 1975 (2); O'Farrell 1972 (1), 1975a (1), 1975b (1), 1975c (1); O'Farrell and Dilley 1974 (1); O'Farrell and others 1972 (1), 1973 (1), 1974 (1), 1975 (1); Price 1965 (2), 1966 (2); Rickard 1964 (1), 1965a (1), 1965b (1), 1965c (1), 1965d (1), 1967a (1), 1967b (1), 1968 (1), 1970a (1), 1970b (1), 1971 (1), 1981 (1), 1982 (1), 1985a (1), 1985b (1), 1985c (1); Rickard and Cline 1965 (1); Rickard and Cushing 1982; Rickard and Garland 1983 (1); Rickard and Haverfield 1965 (1); Rickard and Keough 1968 (1); Rickard and McShane 1984 (1); Rickard and others 1971 (1), 1973a (1), 1973b (1), 1974 (1), 1975 (1), 1976 (1), 1977 (1), 1978 (1), 1982 (1); Rickard and Price 1984 (1); Rickard and Rogers 1983 (1); Rickard and Sauer 1982a (1), 1982b (1); Rickard and Van Scoyoc 1984 (1); Rickard and Warren 1981 (1); Rogers and others 1976 (1); Rogers and Rickard 1975 (1); Rogers and Uresk 1974 (1); Rogers and Woodley 1978 (1); Rotenberry 1980 (2); Rotenberry and others 1975 (1), 1979 (1); Routson and others 1977 (1); Rupp 1969 (2); Sauer and Uresk 1976 (1); Schreiber 1973 (2); Springer 1979 (2), 1982 (2); Steigers and Flinders 1980 (2); Stoel 1976 (2); Uresk 1976 (1); Uresk and Cline 1976 (1); Uresk and others 1976a (1), 1976b (1); Uresk and Rickard 1975 (1); Wildung 1977 (1); Wildung and others 1968 (1), 1971 (1), 1975 (1).

Rooster Comb RNA, Burns District, OR (BLM)

1. Checklist of vascular plants of Steens Mountain
   Current; 1972
   FWS and personal (Karl Urban)
   Karl Urban, Blue Mountain Community College, Pendleton, O
   97801

Saddleback Mountain RNA, Salem District, OR (BLM)

1. Monitoring study on Scoliopus hallii to determine biological requirements for the species and, because it is a key indicator species, to monitor riparian and wet area plant community structure
   Current; 1985
   Salem District BLM Botany Project
   Larry R. Scofield, District Botanist, Bureau of Land Management, Salem, OR 97302

2. Saddleback Mountain RNA monitoring program
   Current; 1985
   Salem District BLM Botany Project
   Larry R. Scofield, District Botanist, Bureau of Land Management, Salem, OR 97302

3. Composition and structure of old-growth forests in the Oregon Coast Range
   Completed; 1974-78
   Oregon State University and NPS
   Glenn Juday, Institute of Northern Forestry, Fairbanks, AK 99700

Juday 1976 (3); Macnab 1958.

Salmo RNA, Colville National Forest, WA (FS)

1. Community types and long-term vegetation permanent sample plots of the Colville National Forest
   Current; 1980
   FS
   Clint Williams, Okanogan National Forest, Okanogan, WA 98840

Wellner [1986]; Williams and Lillybridge 1985 (1).

Silver Lake RNA, North Cascades National Park, WA (NPS)

1. Botanical reconnaissance of Silver Lake
   Completed; 1979-84
   NPS
   Robert Wasem, North Cascades National Park, Sedro Woolley, WA 98284

2. Monitoring of Silver Lake for acidification
   Current; 1979
   NPS, Environmental Protection Agency, and State agencies
   Robert Wasem, North Cascades National Park, Sedro Woolley, WA 98284

3. Monitoring at Silver Lake, including water quality, bathymetric map, bird and mammal survey
   Current; 1979
   NPS
   Robert Wasem, North Cascades National Park, Sedro Woolley, WA 98284

Greene and others 1984 (1); Lesher 1984 (1); Post and others 1971; Shideler 1965.

Sister Rocks RNA, Gifford Pinchot National Forest, WA (FS)

1. Classification of the Silver Fir Zone
   Completed; 1979-82
   FS
   Nancy Halvorsen, Mount Hood National Forest, Gresham, OR 97030

2. Composition, structure, and distribution of subalpine forests in the Washington Cascades
   Completed; 1962-76
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

3. Cone production of upper-slope tree species
   Current; 1961
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

Brockway and others 1983 (1); Carroll and Carroll 1978 (4); Cornelius 1982; Franklin 1966 (2); Franklin and others 1972.

South Fork Willow Creek RNA, Burns District, OR (BLM)

1. Sensitive plants of Steens Mountain
   Current; 1972
   Personal (Karl Urban) and FWS
   Karl Urban, Blue Mountain Community College, Pendleton, OR 97801

Steamboat Mountain RNA, Gifford Pinchot National Forest, WA (FS)

1. Classification of the Silver Fir Zone
   Completed; 1979-82
   FS
   Nancy Halvorsen, Mount Hood National Forest, Gresham, OR 97030

2. Composition, structure, and distribution of subalpine forests in the Washington Cascades
   Completed; 1962-76
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

3. Cone and seed production by upper-slope tree species (subalpine fir and mountain hemlock)
   Current; 1961
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Flora of Steamboat Mountain RNA
   Completed; 1980-81
   Pacific Northwest Natural Area Committee
   Reid Schuller, Department of Natural Resources, Mail Stop EX-13, Olympia, WA 98504

5. Growth, mortality, and succession in subalpine forests
   Current; 1975
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

Bridge 1973; Brockway and others 1983 (1); Franklin 1966 (2), 1968 (3); Franklin and Mitchell 1967 (2); Franklin and others 1974 (3); Greene and Frenkel 1986; Schuller and Frenkel 1981 (4); Schuster and others 1978; Wise 1970.

Stetattle Creek RNA, North Cascades National Park, WA (NPS)

1. Fish surveys of lower Stetattle Creek
   Completed; 1974-76
   NPS
   Robert Wasem, North Cascades National Park, Sedro Woolley, WA 98284

2. Limnological monitoring at Azure Lake
   Current; 1980
   NPS
   Robert Wasem, North Cascades National Park, Sedro Woolley, WA 98284

3. Monitoring water quality at Stetattle Creek
   Current; 1978
   NPS
   Robert Wasem, North Cascades National Park, Sedro Woolley, WA 98284

4. Vegetation mapping by use of remote sensing
   Completed; 1980
   NPS
   Gary Waggoner, Remote Sensing Section, National Park Service, Denver Service Center, Lakewood, CO 80225

5. Vegetation surveys of Stetattle Creek RNA
   Completed; 1979-80
   Western Washington University
   Ron Taylor, Biology Department, Western Washington University, Bellingham, WA 98225

Agee and Wasem [1987] (2, 3, 4); Douglas 1970; Douglas and Ballard 1971; Douglas and Bliss 1977; Waggoner 1980 (4); Wagstaff and Taylor 1980 (5).

Stinking Lake RNA, Malheur National Wildlife Refuge, OR (FWS)

1. Factors affecting the ecology of small mammals on the Malheur National Wildlife Refuge
   Completed; 1973-77
   Oregon State University
   George A. Feldhamer, c/o Zoology Department, Oregon State University, Corvallis, OR 97331

2. Snowy plover survey
   Completed; 1980-81
   FWS
   Steve Herman, The Evergreen College, Olympia, WA 98505

Copeland and Greene 1982; Cornely 1980; Feldhamer 1977 (1); Herman and others 1981 (2); Oregon State Water Resources Board 1969; U.S. Department of the Interior, Fish and Wildlife Service 1981.

Thompson Clover RNA, Wenatchee National Forest, WA (FS)

1. Botanical reconnaissance and monitoring
   Current; 1982
   Personal (Reid Schuller)
   Reid Schuller, Department of Natural Resources, Mail Stop EX-13, Olympia, WA 98504

2. Ecological life history of *Trifolium thompsonii*
   Completed; 1975-77
   University of Washington
   Joan Canfield, c/o A. Kruckeberg, Botany Department, University of Washington, Seattle, WA 98105

3. Community types and long-term vegetation permanent sample plots of the Wenatchee National Forest
   Current; 1979
   FS
   Clint Williams, Okanogan National Forest, Okanogan, WA 98840

Canfield 1977 (2); Hitchcock and others 1961; Tiedemann and others 1977.

Thornton T. Munger RNA, Gifford Pinchot National Forest, WA (FS)

1. Classification of Western Hemlock Zone
   Current; 1982-86
   FS
   Nancy Halvorsen, Mount Hood National Forest, Gresham, OR 97030

2. Composition, structure, and distribution of subalpine forests in the Washington Cascades
   Completed; 1962-76
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

3. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

4. Dynamics of coarse woody debris in Douglas-fir forests
   Completed; 1978-82
   NSF and Oregon State University
   Phil Sollins, Forest Science Department, Oregon State University, Corvallis, OR 97331

5. Ecological monitoring of long-term effects of energy development
   Completed; 1980-84
   DOE
   W.T. Hinds, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, WA 99352

6. Growth, mortality, and succession in an old-growth Douglas-fir forest
   Current; 1947
   FS
   Dean DeBell, Forestry Sciences Laboratory, Olympia, WA 98502

7. Mammal and bird monitoring in old-growth wildlife habitats
   Current; 1983
   FS
   S.D. West, University of Washington, Seattle, WA 98105

8. Seed survival of Douglas-fir in forest floor
   Completed; 1924-43
   FS
   Dean DeBell, Forestry Sciences Laboratory, Olympia, WA 98502

9. Vegetation classification of old-growth wildlife habitat
   Current; 1983
   FS
   Tom Spies, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

10. Flora of the Thornton T. Munger RNA
    Completed; 1980-82
    Pacific Northwest Natural Area Committee
    Reid Schuller, Department of Natural Resources, Mail Stop EX-13, Olympia, WA 98504

Carroll and Carroll 1978 (3); DeBell and Franklin 1986 (6); Franklin 1966 (2); Franklin and DeBell 1986 (6); Franklin and Hemstrom 1981; Franklin and others 1972, 1986b (6); Hinds 1984 (5); Hinds and others 1981; Isaac 1940, 1943; Kemp and Schuller 1982 (10); King 1961 (6); MacSiurtain 1979; McShane and others 1983 (5); Old-Growth Definition Task Group 1986 (9); Skalski and others 1981 (5); Sollins 1982 (4); Spies and others 1985 (9); Steele 1952; Steele and Worthington 1955 (6); Thomas and others 1981 (5); Topik and others 1985 (1); Waring and Franklin 1979.

Tiffany Mountain Proposed RNA, Okanogan National Forest, WA (FS)

1. Environmental impacts of wildland recreation
   Current; 1984
   Personal (Paul Saunders)
   Paul Saunders, Washington State University, Pullman, WA 99164-6410

2. Community types and long-term vegetation permanent sample plots of the Okanogan National Forest
   Current; 1976
   FS
   Clint Williams, Okanogan National Forest, Okanogan, WA 98840

Williams and Lillybridge 1983 (2).

Torrey-Charlton Proposed RNA, Willamette and Deschutes National Forests, OR (FS)

1. Growth and yield of mountain hemlock stands
   Current; 1976
   FS
   Joseph Means, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

2. Stress-induced wave mortality in subalpine forest ecosystems
   Current; 1981
   NSF and Oregon State University
   Richard Waring, Forest Science Department, Oregon State University, Corvallis, OR 97331

3. Vegetation of Torrey Lake mire
   Completed; 1976-86
   FS and Oregon State University
   Robert Frenkel, Geography Department, Oregon State University, Corvallis, OR 97331

Boone 1982 (2); Boone and others 1986 (2); Cromack 1985; Frenkel and others 1986 (3); Matson 1983; Matson and Boone 1984 (2); Matson and Waring 1984 (2); Waring and others 1986 (2).

Tum Tum Lake RNA, Burns District, OR (BLM)

1. Snowy plover study
   Completed; 1980-81
   FWS
   Steve Herman, The Evergreen College, Olympia, WA 98505

Herman and others 1981 (1).

Turnbull Pine RNA, Turnbull National Wildlife Refuge, WA (FWS)

1. Abundance, cover frequency, and biomass data; some mapping of the trees and larger communities (student project)
   Completed; 1976
   Turnbull Laboratory for Ecological Studies
   Robert Carr, Director, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

2. Analysis of the stomach contents of wandering garter snakes (*Thamnophis elegans vagrans*) from eastern Washington
   Completed; 1978-82
   Theodore Roosevelt Memorial Fund and the Gaige Fund
   Charles R. Peterson, Department of Anatomy, University of Chicago, Chicago, IL 60637

3. Aquatic insects of the Turnbull National Wildlife Refuge
   Current; 1968
   Eastern Washington University
   Raymond Soltero, Biology Department, Eastern Washington University, Cheney, WA 99004

4. Baseline limnological data for Middle Findley Lake, Turnbull National Wildlife Refuge
   Completed; 1985
   Turnbull Laboratory for Ecological Studies
   Don Nichols, Biology Department, Eastern Washington University, Cheney, WA 99004

5. Body temperature variation in free-ranging garter snakes (*Thamnophis elegans vagrans* and *Thamnophis sirtalis fitchi*)
Completed; 1978-82
Washington State University
Raymond Soltero, Biology Department, Eastern Washington University, Cheney, WA 99004

6. Cercaria study of the snails of the Findley Lakes
Completed; 1976-77
Eastern Washington University
Bruce Z. Lang, Eastern Washington University, Cheney, WA 99004

7. Chemical, physical, and biological characteristics of Upper Findley Lake (student project)
Completed; 1976
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

8. Effects of season and host size on infection rates of Digenea in the snail *Lymnaea stagnalis*
Completed; 1969-71
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

9. Endoparasite faunal dynamics on black bullheads (*Ictalurus melas*)
Completed; 1972-74
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

10. Flora of the Turnbull Pine RNA
Current; 1975
Eastern Washington University
Robert Carr, Chairman, Biology Department, Eastern Washington University, Cheney, WA 99004

11. Food partitioning by terrestrial organisms (student project)
Completed; 1976
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

12. Free swimming invertebrate communities of vernal pools in eastern Washington
Completed; 1982-84
University of Idaho and Turnbull Laboratory for Ecological Studies
Fred Rabe, Department of Biological Sciences, University of Idaho, Moscow, ID 83843

13. Interrelationships of grazing, rodent densities, and predation of artificial avian nests
Completed; 1972-74
Eastern Washington University
Raymond Soltero, Biology Department, Eastern Washington University, Cheney, WA 99004

14. Lake metabolism: light and dark bottle study of upper Findley Lake (student project)
Completed; 1976
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

15. Life history of a Cephalogonimus (Trematoda from Ambystoma tigrinum)
Completed; 1969-72
Eastern Washington University
Raymond Soltero, Biology Department, Eastern Washington University, Cheney, WA 99004

16. Myxomycetes on ponderosa pine logs
Completed; 1969-70
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

17. Observations of the aquatic invertebrates on a small pond in spring, 1976, after a drought year (student project)
Completed; 1976
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

18. Predatory food habits of Formica obscuripes on Turnbull Pine RNA
Completed; 1976-78
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

19. Relationship between the density levels of the beetle _Chrysolina gemellata_ and its food plant _Hypericum perforatum_ along upper Findley Lake (student project)
Completed; 1976
Eastern Washington University
Robert Carr, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

20. Upper Findley Lake Coleoptera study (student project)
Completed; 1976
Eastern Washington University
Robert Carr, Director, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

21. Vegetational analysis of the Turnbull Pine RNA (student project)
Completed; 1976
Eastern Washington University
Robert Carr, Director, Turnbull Laboratory for Ecological Studies, Eastern Washington University, Cheney, WA 99004

22. Vegetation comparison on grazed and protected sites
Completed; 1970-72
Eastern Washington University
Raymond Soltero, Biology Department, Eastern Washington University, Cheney, WA 99004

Bennington 1972 (22); Bretz 1959; Clevenger 1983; Current 1974 (9); Donaldson and Giese 1968; Dronen 1970 (15); Dronen and Lang 1974 (15); Franklin and others 1972; Kulp and Rabe 1984 (12); Lang and Dronen 1970; Lessor 1978 (18); Morig 1972 (8); Nichols 1985 (4); Peterson 1982 (2, 5), in press (2, 5); Zabel 1970 (16).

Twin Creek RNA, Olympic National Park, WA (NPS)

1. Community ecology of the Olympic Rain Forest
Completed; 1970-74
NSF
Richard Fonda, Biology Department, Washington State University, Bellingham, WA 99163

2. Ecology of the Roosevelt elk
Current; 1976
NPS
Ed Starkey, National Park Service, Cooperative Park Studies Unit, College of Forestry, Oregon State University, Corvallis, OR 97331

3. Precipitation chemistry and ecosystem function in Olympic National Park: baseline research for acid precipitation studies
   Current; 1984
   NPS
   Charles Grier, College of Forest Resources, University of Washington, Seattle, WA 98105

4. Use of six ecosystem parameters to detect low levels of airborne pollutants
   Current; 1984
   DOE
   Mark Harmon, Forest Science Department, Oregon State University, and Sarah Greene, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

5. Forest types of Olympic National Park
   Current; 1978
   NPS
   Bradley Smith, Forest Science Department, Oregon State University, Corvallis, OR 97331

Baker and others 1984 (4); Crandell 1964; Danner 1955; Fonda 1974 (1); Franklin and others 1972; Henderson and others 1978 (5); Jenkins 1979 (2), 1981 (2); Jenkins and Starkey 1980a (2), 1980b (2), 1982 (2); Leslie 1982 (2); Smith and Henderson 1986 (5); Wiersma and others 1985 (4).

Upper Elk Meadows RNA, Eugene District, OR (BLM)

Curtis 1986d.

Vance Knoll Proposed RNA, Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of grasslands
   Current; 1978
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

West Razz Lake Proposed RNA, Wallowa-Whitman National Forest, OR (FS)

1. Ecological classification of subalpine mountain meadows
   Current; 1980
   FS
   Charles Johnson, Wallowa-Whitman National Forest, Baker, OR 97814

Wet Weather Creek Proposed RNA, Olympic National Forest, WA (FS)

1. Plant associations and habitat types of the Olympic National Forest
   Current; 1982
   FS
   Jan Henderson, Olympic National Forest, Box 2288, Olympia, WA 98507

Wheeler Creek RNA, Siskiyou National Forest, OR (FS)

1. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
   Completed; 1976-78
   NSF and University of Oregon
   George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

2. Mammals of the Oregon coast
   Completed; 1970-81
   University of Puget Sound and private
   Chris Maser, Bureau of Land Management, 3200 Jefferson Way, Corvallis, OR 97331

Carroll and Carroll 1978 (1); Dott 1971; Dyrness and others 1973; Franklin and others 1972; Maser and others 1981 (2); Parker 1973.

Wildcat Mountain RNA, Willamette National Forest, OR (FS)

1. Carbon and nutrient budgets in forests of the Pacific Northwest
   Current; 1973
   NSF and Oregon State University
   Charles Grier, College of Forest Resources, University of Washington, Seattle, WA 98105

2. Cone and seed production by upper-slope conifers (noble fir, Pacific silver fir, and mountain hemlock)
   Current; 1961
   FS
   Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

3. Disjunct flora of the western Cascade peaks
   Completed; 1963-68
   University of Oregon
   James Hickman, Swarthmore College, Swarthmore, PA 19081

4. Distribution of birds and mammals in relation to plant communities
Completed; 1973-81
NSF and private
Ron Nussbaum, Zoology Department, University of Michigan, Ann Arbor, MI 48109

5. Distribution and role of conifer needle endophytes (fungi on needle surfaces)
Completed; 1976-78
NSF and University of Oregon
George Carroll, Biology Department, University of Oregon, Eugene, OR 97403

6. Ecological monitoring of long-term effects of energy development
Completed; 1980-84
DOE
W.T. Hinds, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, WA 99352

7. Effects of environment on forest leaf areas and productivity
Completed; 1976
NSF and Oregon State University
Richard Waring, Forest Science Department, Oregon State University, Corvallis, OR 97331

8. Effects of environment on decomposition and nutrient-cycling processes
Completed; 1974-76
NSF and Oregon State University
Kermit Cromack, Forest Science Department, Oregon State University, Corvallis, OR 97331

9. Environmental relations of forest communities in the western Cascades of Oregon
Current; 1970
NSF and Oregon State University
Arthur McKee, Forest Science Department, Oregon State University, Corvallis, OR 97331

10. Growth and yield of noble fir stands
Current; 1976
FS
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

11. Habitat type classification for western Cascade forests
    Completed; 1967-76
    FS
    Jerry Franklin, Forestry Sciences Laboratory, 3200
     Jefferson Way, Corvallis, OR 97331

12. Relation of site index to habitat types in the Pacific
     Silver Fir Zone
    Current; 1967
    FS
    Jerry Franklin, Forestry Sciences Laboratory, 3200
     Jefferson Way, Corvallis, OR 97331

13. Distribution and abundance of lichens in old-growth conifer
     stands
    Completed; 1977-80
    NSF
    Larry Pike, 38563 Wendling Road, Marcola, OR 97454

14. Meadow invasion by _Abies procera_
    Current; 1986
    Personal (Michael Trayner) and Oregon State University
    Michael Trayner, Environmental School of Forestry,
     Syracuse, NY 13210

Carkin and others 1978 (2); Carroll and Carroll 1978 (5); Dyrness and others 1976 (11); Franklin 1968 (2), 1983 (10); Franklin and others 1972, 1974 (2), 1986b (10); Fujimori and others 1976 (7); Hawk and others 1978 (10, 11); Hemstrom and others 1982, 1985; Herman and others 1978; Hickman 1968 (3), 1976 (3); Hinds 1984 (6); Howe 1978 (13); Klopsch and others 1979; Vale 1981; Waring and Franklin 1979; Webb and others 1983; Weirs and Nussbaum 1975; Zobel and others 1976 (9).

Willamette Floodplain RNA, William L. Finley National Wildlife Refuge, OR (FWS)

1. Assessment of burning prairie vegetation in Willamette
     Valley
    Current; 1982
    FWS
    Robert Frenkel, Geography Department, Oregon State
     University, Corvallis, OR 97331

2. Composition, succession, and productivity in Willamette
     Valley grasslands
    Current; 1971
    Pacific Northwest Natural Area Committee
    Jerry Franklin, Forestry Sciences Laboratory, 3200
     Jefferson Way, Corvallis, OR 97331

3. Effects of burning on prairie ecosystems
Current; 1972
Pacific Northwest Natural Area Committee
Jerry Franklin, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331

4. Vegetation ecology of a Fraxinus latifolia community
Current; 1981
Oregon State University
Robert Frenkel, Geography Department, Oregon State University, Corvallis, OR 97331

5. Relation of water table to Fraxinus communities
Current; 1983
Personal (Diana Bodker)
Diana Bodker, General Science, Oregon State University, Corvallis, OR 97331

Balster and Parsons 1968; Heinitz 1982 (4); Landa 1977; Parsons and others 1967.

Wolf Creek RNA, Okanogan National Forest, WA (FS)

1. Community types and long-term permanent sample plots of the Okanogan National Forest
Current; 1976
FS
Clint Williams, Okanogan National Forest, Okanogan, WA 98840

Franklin and others 1972; Williams and Lillybridge 1983 (1).

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Appendix: List of Research Natural Areas

All established RNA's are listed by State (Oregon first, then Washington) and agency. More than 70 proposed RNA's are in various stages of the planning process. Only the proposed RNA's with ongoing research are listed. Areas are not given for proposed RNA's because the RNA's have not yet been officially established.

Agency and address	Research Natural Area	Area
		Hectares (acres)
	OREGON	
	Bureau of Land Management	
Burns District, Bureau of Land Management 74 South Alvord Street Burns, OR 97720	East Kiger Plateau	502 (1,240)
	Little Blitzen	1028 (2,539)
	Little Wildhorse	97 (240)
	Long Draw	198 (489)
	Mickey Basin	227 (561)
	Pueblo Foothills	1020 (2,519)
	Rooster Comb	291 (719)
	Silver Creek	259 (640)
	South Fork Willow Creek	92 (227)
	Tum Tum Lake	616 (1,522)
Coos Bay District,Bureau of Land Management 333 South Fourth Street Coos Bay, OR 97420	Cherry Creek	239 (590)
Eugene District, Bureau of Land Management Box 10226 Eugene, OR 97401	Camas Swale	113 (279)
	Fox Hollow	66 (161)
	Mohawk	113 (294)
	Upper Elk Meadows	82 (205)
Lakeview District, Bureau of Land Management Box 151 Lakeview, OR 97630	Lost Forest	3628 (8,961)
Medford District, Bureau of Land Management 3040 Biddle Road Medford, OR 97501	Brewer Spruce	85 (210)
	Woodcock Bog	112 (277)

rineville District, Bureau of	Horse Ridge	243 (600)
Land Management	The Island	66 (162)
ox 550		
rineville, OR 97754		
oseburg District, Bureau of	Beatty Creek	160 (395)
Land Management	North Myrtle Creek	97 (240)
77 N.W. Garden Valley Road	Myrtle Island	11 (27)
oseburg, OR 97470	Tater Hill	68 (168)
alem District, Bureau of	The Butte	16 (40)
Land Management	Carolyn's Crown	105 (259)
717 Fabry Road S.E.	Grass Mountain	295 (729)
alem, OR 97302	High Peak-Moon Creek	618 (1,526)
	Little Sink	32 (79)
	Saddleback Mountain	55 (136)
ale District, Bureau of Land	Honeycombs	4830 (11,930)
Management	Jordan Craters	12709 (31,391)
ox 700	Mahogany Mountain	130 (321)
ale, OR 97618	Stockade Mountain	308 (761)

Department of the Navy

epartment of the Navy	Boardman	2095 (5,175)
estern Division, Naval		
Facilities Command		
uilding 138, Room 215		
aval Station		
eattle, WA 98115		

National Forests

eschutes National Forest	Metolius	533 (1,317)
645 Highway 20 East	Pringle Falls	545 (1,346)
end, OR 97701	Little Cultus Lake proposed	
	Torrey-Charlton proposed	
remont National Forest	Goodlow Mountain	510 (1,260)
ox 551		
akeview, OR 97630		
alheur National Forest	Canyon Creek	283 (699)
39 N.E. Dayton		
ohn Day, OR 97845		
ount Hood National Forest	Bagby	227 (561)
955 N.W. Division	Bull Run	146 (361)
resham, OR 97030	Mill Creek	330 (815)

Ochoco National Forest Box 490 Prineville, OR 97754	Ochoco Divide	777 (1,919)
	The Island	21 (52)
Rogue River National Forest 333 W. 8th Street Medford, OR 97501	Abbott Creek	1077 (2,660)
	Ashland	570 (1,408)
Siskiyou National Forest Box 440 Grants Pass, OR 97526	Coquille River Falls	202 (499)
	Port-Orford-Cedar	454 (1,121)
	Wheeler Creek	135 (333)
	Hoover Gulch proposed	
Siuslaw National Forest Box 1148 Corvallis, OR 97339	Flynn Creek	271 (669)
	Neskowin Crest	476 (1,176)
Umpqua National Forest Box 1008 Roseburg, OR 97470	Limpy Rock	760 (1,877)
Wallowa-Whitman National Forest Box 907 Baker, OR 97814	Indian Creek	401 (990)
	Alum Beds proposed	
	Bills Creek proposed	
	Boner Flat proposed	
	Craig Mountain proposed	
	Duck Lake proposed	
	Government Draw proposed	
	Lightning Creek proposed	
	Little Granite proposed	
	Pleasant Valley proposed	
	Vance Knoll proposed	
	West Razz Lake proposed	
Willamette National Forest Box 10607 Eugene, OR 97440	Gold Lake Bog	188 (464)
	Middle Santiam	463 (1,144)
	Olallie Ridge	291 (719)
	Wildcat Mountain	405 (1,000)
	Hagan proposed	
	Torrey-Charlton proposed	
Winema National Forest Box 1390 Klamath Falls, OR 97601	Blue Jay	85 (210)

Wildlife Refuges

Hart Mountain National Wildlife Refuge Box 111 Lakeview, OR 97630	Poker Jim Ridge	259 (640)
Malheur National Wildlife Refuge Box 113 Burns, OR 97720	Harney Lake	12000 (29,640)
	Stinking Lake	626 (1,546)
William L. Finley National Wildlife Refuge Route 2, Box 208 Corvallis, OR 97333	Maple Knoll	40 (99)
	Pigeon Butte	28 (69)
	Willamette Floodplain	97 (240)

WASHINGTON

Bureau of Land Management

Spokane District, Bureau of Land Management 4217 E. Main Avenue Spokane, WA 99202	Hot Lakes	32 (79)

Department of Energy

Department of Energy Batelle Memorial Institute Pacific Northwest Laboratories Richland, WA 99352	Rattlesnake Hills	33350 (75,000)

National Forests

Colville National Forest 695 S. Main Colville, WA 99114	Maitlen Creek	254 (628)
	Salmo	563 (1,391)
Gifford Pinchot National Forest 500 W. 12th Street Vancouver, WA 98660	Butter Creek	226 (558)
	Cedar Flats	275 (679)
	Goat Marsh	484 (1,195)
	Sister Rocks	87 (215)
	Steamboat Mountain	567 (1,400)
	Thornton T. Munger	478 (1,181)

Mount Baker-Snoqualmie National Forest 1022 First Avenue Seattle, WA 98104	Lake Twenty-Two	320 (790)
	Long Creek	259 (640)
	North Fork Nooksack	569 (1,405)
	Chowder Ridge proposed	
	Green Mountain proposed	
	Lily Lake proposed	
	Perry Creek proposed	
Okanogan National Forest 1240 S. Second Street Okanogan, WA 98840	Wolf Creek	60 (148)
	Maple Mountain proposed	
	Tiffany Mountain proposed	
Olympic National Forest Box 2288 Olympia, WA 98507	Quinault	594 (1,467)
	Buckhorn Mountain proposed	
	Wet Weather Creek proposed	
Umatilla National Forest 2517 S.W. Hailey Avenue Pendleton, OR 97801	Pataha Bunchgrass	21 (52)
	Rainbow Creek	243 (600)
Wenatchee National Forest Box 811 Wenatchee, WA 98801	Meeks Table	28 (69)
	Thompson Clover	81 (200)
	Eldorado Creek proposed	

National Parks

Mount Rainier National Park Tahoma Woods Star Route Ashford, WA 98304	Butter Creek	809 (1,982)
North Cascades National Park Sedro Woolley, WA 98284	Boston Glacier	1251 (3,090)
	Pyramid Lake	48 (119)
	Silver Lake	683 (1,687)
	Stetattle Creek	5605 (13,850)
Olympic National Park 600 East Park Street Port Angeles, WA 98362	Hades Creek	227 (556)
	Higley Creek	194 (475)
	Jackson Creek	65 (159)
	Twin Creek	40 (98)

Wildlife Refuges

Columbia National Wildlife Refuge P.O. Drawer F Othello, WA 99344	Drumheller Sagebrush Steppe	269 (660)

Little Pend Oreille Wildlife Refuge Route 1 Colville, WA 99114	Baird Basin	65 (160)
	Varline Grove	60 (147)
Ridgefield National Wildlife Refuge 1309 N.E. 134th Street, Room C Vancouver, WA 98685	Blackwater Island	52 (129)
Turnbull Pine National Wildlife Refuge Route 3, Box 107 Cheney, WA 99004	Pine Creek	65 (160)
	Turnbull Pine	81 (200)
Willapa National Wildlife Refuge 1309 N.E. 134th Street, Room C Vancouver, WA 98685	Diamond Point	36 (88)

Greene, Sarah E.; Blinn, Tawny; Franklin, Jerry F. Research Natural Areas in Oregon and Washington: past and current research and related literature. Gen. Tech. Rep. PNW-197. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 1986. 115 p.

This publication lists all completed and current research projects in Research Natural Areas in Oregon and Washington and in those few Research Natural Areas in Idaho that are administered by National Forests in Oregon. The list includes project title, status, source of funding, and principal investigator and address. A list of publications pertaining to Research Natural Areas is also included. Where possible, publications and research projects are correlated. The publication outlines the scientific use and importance of Research Natural Areas as research sites for applied and basic studies. More than 200 projects and 500 publications are included for 88 Research Natural Areas and 23 proposed Research Natural Areas.

Keywords: Natural areas (research), bibliographies (research natural area), land management, research.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Application of Geotechnical Data to Resource Planning in Southeast Alaska

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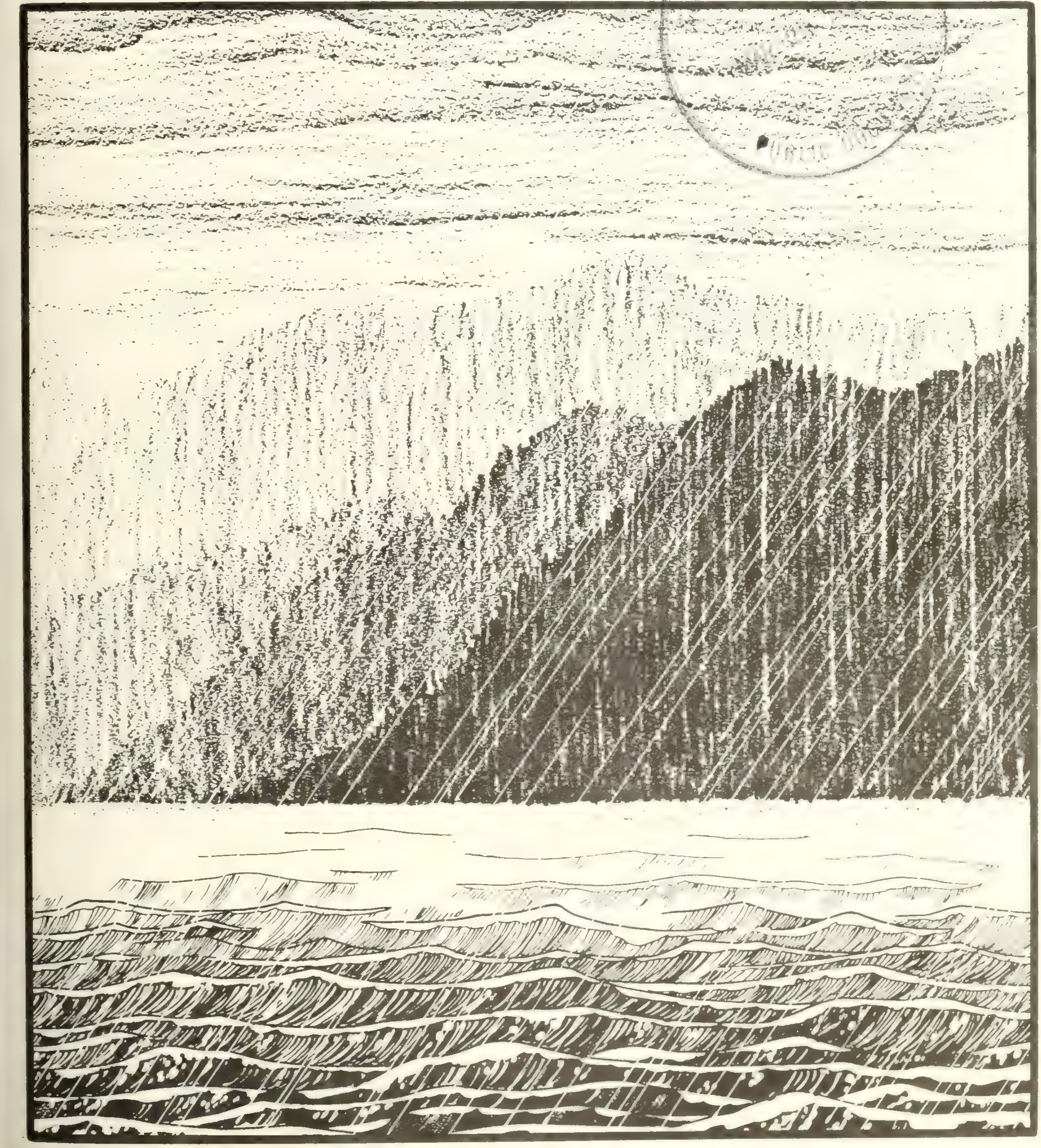

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Abstract

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Recent quantification of engineering properties and index values of dominant soil types in the Alexander Archipelago, southeast Alaska, have revealed consistent diagnostic characteristics useful to evaluating landslide risk and subgrade material stability before timber harvesting and low-volume road construction. Shear strength data are summarized and grouped by Soil Conservation Service soil series, by the Unified Soil Classification system, and by geologic origin. Such groupings allow the selection of strength parameters for slope and subgrade stability analyses based on existing knowledge of the terrain and on available inventory data. Parameters are expressed by mean and minimum values so that both average and conservative evaluations can be made, depending on management requirements. Engineering procedures were used to incorporate the parameters into planning and project-level investigations to identify areas of unstable terrain, to assess levels of landslide risk, and to define suitability of materials for road construction.

Keywords: Slope stability, subgrade stability, soil properties (physical), southeast Alaska, Alaska (southeast).

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Introduction

Slope failures in coastal Alaska occur primarily as debris avalanches in shallow hillslope depressions. The susceptibility of such sites to failure is a function of slope gradient, overburden depth,[1] soil strength, and the soil's ability to absorb and transmit water. A controlling factor in almost all failures is the development of a temporary water table in these depressions during high-intensity, long-duration rainfall. Positive porewater pressures generated by this subsurface water reduce soil effective stresses[2] within the depressions and may either directly initiate a landslide or render the site susceptible to failure during some external loading event, such as windthrow or rockfall.

Timber harvesting in coastal Alaska usually requires construction of access and haul roads. These roads must be built in unfavorable circumstances: weather and soil moisture conditions are poor throughout the year, and freezing is often a possibility; many roads are built on muskeg that, during normal construction, would be removed or avoided; and access for equipment is costly and difficult. In spite of these problems, roads are being built, and planning for the roads must be based on available information on using naturally occurring vs. imported soil and rock.

This paper discusses the developing geotechnical and hydrological data bases and shows how the information, coupled with simplified engineering analysis procedures, can be used in resource allocation and project planning studies. Techniques are suggested for analyzing natural slopes using the infinite slope method and for analyzing slopes created by road cuts using an approximate circular arc procedure. These techniques are fairly well developed. Only general guidelines for using natural materials for roadway construction are given.

Results of analyses are intended only for resource allocation and for planning studies. Stability evaluations for specific sites and subgrade strength analyses require detailed, site-specific investigations.

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[1] Overburden depth refers to the residual and colluvial soils and organic debris overlying bedrock and dense glacial till.

[2] Effective stress is a force per unit area that tends to cause compression or deformation of the solid phase of the soil. In this case, the effective stress is due to the weight of the solid in the depressions exerted along an impermeable bedrock or glacial till surface.

The Developing Data Base

Preliminary data for engineering properties and index properties of the most widely occurring soils in the Tongass National Forest were determined by Schroeder and Filz (1981) and by Schroeder (1983). These studies provide the basic soil materials data used in this paper. Forty sample sites were located with the assistance of soils and engineering specialists from the Tongass National Forest (fig. 1). Undisturbed Shelby tube samples were collected at each site, and laboratory tests were conducted to evaluate index properties and to measure effective stress-strength parameters. Results for each site are shown in tables 1 and 2. Most of the sampled materials, except those obtained from elevated marine deposits (sites 17-20, table 1), were gravels and sands, but they contained an appreciable quantity of nonplastic silt. The marine deposits had a very low coarse-particle content and were predominantly nonplastic silts, but clay-sized particles were present locally in significant amounts (> 50 percent). Unit weights were variable, but all soils were moderately overconsolidated and most exhibited high angles of internal friction. For most materials sampled, there was a modest but important (for strength at critical sites) degree of cohesion present. For the most part, index properties (Atterberg Limits) of these soils were of little value for judging strength characteristics. Cohesion was only moderately influenced by the Plasticity Index and, in general (except for marine deposits), was very low. No significant effects of organic content on cohesive strength were measured. Angle of internal friction is not regularly related to the Plasticity Index; however, it may be conservatively estimated using the relation developed by Bjerrum and Simons (1960).

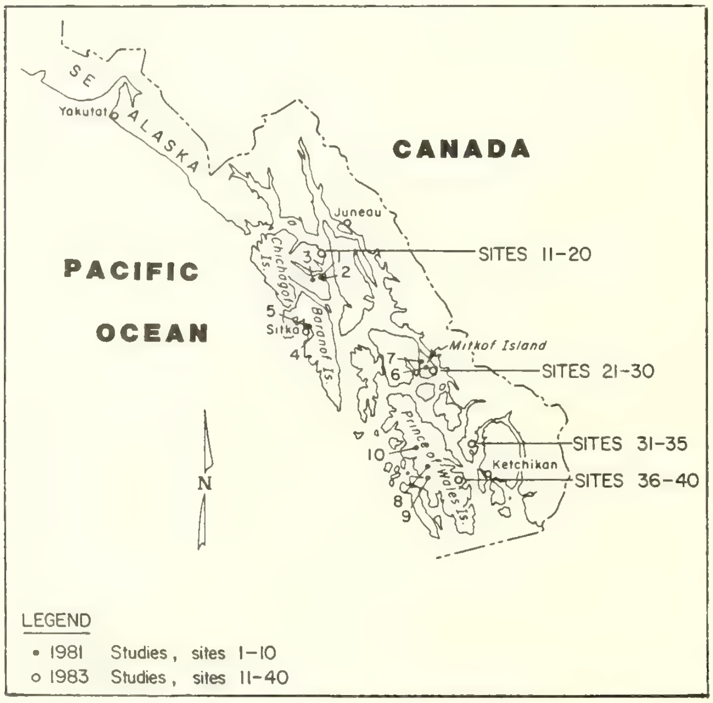

Figure 1—Forty sample site locations for 1981 and 1983 studies in southeast Alaska.

Table 1—Results of index property tests of undisturbed southeast Alaska forest soils, by site number

		Particle size distribution					Atterberg Limits					
Site no.	Soil series 1/	2 mm	Sand 2-0.05 mm	Silt 0.05-0.002 mm	Clay 0.002 mm	Total fines 0.05 mm	LL 2/	PL 3/	PI 4/	Specific gravity of solids	Organic content	Unified Soil Classification
				Percent							Percent	
1	Kupreanof	3	30	--	--	67	91	60	31	2.68	-	MH
2	Tolstoi	45	42	--	--	13	100	66	34	2.79	-	GM
3	Karta	31	55	--	--	14	108	79	29	2.72	--	SM
4	Shelikof	1	62	--	--	37	155	103	52	2.67	--	SM
5	Sitka	--	64	--	--	36	154	115	39	2.74	--	SM
6	Tokeen	17	58	--	--	25	142	64	78	2.71	--	SC
7	Gunnuck	9	36	--	--	55	23	18	5	2.76	--	CL-ML
8	Karta	23	52	--	--	25	81	46	35	2.70	--	SM
9	Ulloa	17	51	--	--	32	100	78	22	2.69	--	SM
10	Wadleigh	23	38	--	-	39	87	45	42	2.68	--	SM
11	Wadleigh	23.9	31.0	21.8	23.3	45.1	40	25	15	2.77	1.0	SC
12	Wadleigh	23.8	26.4	23.2	26.6	49.8	32	22	10	2.76	1.1	SC
13	Wadleigh	39.5	27.5	21.0	12.0	33.0	78	57	21	2.75	4.4	GM
14	Wadleigh	30.5	28.4	16.9	24.2	41.1	27	19	8	2.79	0.7	CC
15	Wadleigh	49.4	22.7	12.3	15.6	27.9	27	18	9	2.78	0.9	CC
16	Marine clay	64.9	16.5	7.8	10.8	18.6	47	28	19	2.80	4.3	CC
17	Marine clay	--	3.0	28.1	68.9	97.0	56	29	27	2.85	0.5	CH
18	Marine clay	4.3	28.2	42.1	25.4	67.5	30	21	9	2.85	1.0	ML
19	Marine clay	--	3.3	28.4	68.3	96.7	54	29	25	2.86	0.9	CH
20	Marine clay	1.3	7.2	48.2	43.3	91.5	48	28	20	2.76	0.9	ML
21	Mitkof	31.0	49.3	16.8	2.8	19.6		Nonplastic		2.81	6.2	SM
22	Mitkof	4.6	49.5	38.0	7.9	45.9	68	57	11	2.72	9.2	SM
23	Kupreanof	31.2	43.3	21.1	4.4	25.5	62	49	13	2.67	6.6	SM
24	Kupreanof	45.4	33.6	17.1	3.9	21.0		Nonplastic		2.77	2.2	GM
25	Kupreanof	--	39.6	47.1	13.3	60.4	77	52	25	2.81	5.0	MH
26	Mitkof	--	39.6	49.1	11.3	60.4	100	75	25	2.89	7.8	MH
27	Mitkof	10.2	64.6	19.2	6.0	25.2		Nonplastic		2.93	0.5	SM
28	Mitkof	25.7	55.7	13.7	4.9	18.6		Nonplastic		2.82	3.2	SM
29	Mitkof	34.4	39.1	20.6	5.9	26.5	82	65	17	2.79	9.4	SM
30	Mitkof	3.2	43.3	43.2	10.3	53.5	78	67	11	2.60	13.4	MH
31	Traitors (Vixen)	19.3	21.4	52.3	7.0	59.3		Nonplastic		2.86	1.8	ML
32	Traitors (Vixen)	--	20.6	68.6	10.8	79.4		Nonplastic		2.93	3.3	ML
	Traitors (Vixen)	--	16.5	72.5	11.0	83.5		Nonplastic		2.85	1.7	ML
34	Traitors (Vixen)	3.5	15.9	70.4	10.2	80.6		Nonplastic		2.85	2.1	ML
35	Traitors (Vixen)	2.7	16.1	71.1	10.1	81.2		Nonplastic		2.80	1.8	ML
36	Traitors (Vixen)	44.3	23.9	26.4	5.4	31.8	102	79	23	2.82	8.4	GM
37	Tolstoi	31.3	30.6	31.3	6.8	38.1	114	92	21	2.59	12.8	GM
38	Tolstoi	32.0	32.0	31.1	4.9	36.0	149	110	39	2.56	14.8	SM
39	Tolstoi	44.3	21.6	29.1	5.0	34.1	102	71	31	2.77	10.5	GM
40	Tolstoi	25.5	32.3	35.4	6.8	42.2	84	65	19	2.70	9.4	SM

1/ Tentative Soil Conservation Service names.

2/ Liquid limit.

3/ Plastic limit.

4/ Plasticity index.

A wide variety of material was sampled. Variability in test results between types and even within types of material was great and made strict comparisons difficult. There were, however, enough similarities in engineering characteristics to allow reasonable groupings by (1) Soil Resource Inventory series, (2) Unified Soil Classification system (USC), and (3) geologic origin designations (tables 3, 4, and 5, respectively). Because of difficult logistics and the large geographic area sampled, the number of samples for each grouping was not large (minimum 4, maximum 7); statistical evaluation of the data therefore has limitations. The data do, however, provide estimates of properties and their range within groupings. The mean and the fifth percentile of soil strength variables for each grouping were estimated using laboratory test results (tables 6, 7, and 8). The fifth percentile is the value such that 5 percent of the values of a normally distributed sample population are less than this. The normal distribution of these engineering properties has been demonstrated in the Pacific Northwest under similar geomorphic and climatic conditions (Schroeder and Alto 1983). The fifth percentile therefore represents a reasonable estimate of a minimum property value. The mean values may be used for general assessment of soil behavior; the fifth percentile should be used in sensitive situations where the consequences of occasional failures are especially undesirable.

Hydrologic data have been quantified for only a few critical areas, but the general relations to site stability are known. Existing data can be used effectively to estimate the influence of storms on slope stability for planning-level risk assessment. Swanston (1967) developed initial data on ground-water level fluctuations in permeable materials within shallow upslope depressions at Hollis, Prince of Wales Island, and related them to 24-hour rainfall intensities. The materials were Karta soils (which classify as SM soils by the USC system) derived from the weathering of glacial tills. These soils have a low content of nonplastic silt and consequently exhibit high permeabilities. The characteristics of these materials are represented by sites 3 and 8 in table 1. Because of the high permeabilities, the response of water table level to rainfall intensity is rapid. The relation between ground-water height (h in inches) and 24-hour rainfall intensity (R in inches per day) is curvilinear (fig. 2) and is expressed by the equation:

$$h = 7.66 - \frac{0.331}{R} + 6.51R \; . \tag{1}$$

As rainfall intensity increases, water level rises rapidly at first, but at a decreasing rate as rainfall continues, and reaches an upper limit determined by the thickness of the soil profile.

More detailed work in progress at Kennel Creek on Chichagof Island (Sidle in press, Sidle and Swanston 1980, 1981) indicates a similar general response of degree of saturation to rainfall intensity for less pervious materials in the Kupreanof Series (SM-MH soils in the USC system) (sites 23 and 26 in table 2). The response appears, however, to be much more closely related to maximum 2-hour rainfall intensity, antecedent 24-hour rainfall, and duration of a storm.

Table 2—Results of consolidated, undrained triaxial shear tests of undisturbed southeast Alaska forest soils, by site number

Site no.	Soil series 1/	Water content	Dry unit weight	Angle of internal friction (effective)	Cohesion (effective)	Pore pressure parameter A
		percent	lb/ft^3	degrees	lb/ft^2	
1	Kupreanof	91	48.4	36.0	292	--
2	Tolstoi	33	91	43.0	104	--
3	Karta	23	106.3	35.1	125	--
4	Shelokof	143	33.7	24.9	230	--
5	Sitka	154	33.1	38.9	251	--
6	Tokeen	51	68.1	35.6	104	--
7	Gunnuck	16	119	43.7	251	--
8	Karta	48	73.2	37.5	167	--
9	Ulloa	57	64.9	34.4	125	--
10	Wadleigh	49	64.3	32.4	104	--
11	Wadleigh	22.0	113.4	40.7	80	0.21
12	Wadleigh	20.0	106.2	33.1	360	.02
13	Wadleigh	25.0	88.8	37.4	180	.20
14	Wadleigh	12.5	106.3	33.7	360	.06
15	Wadleigh**	18.0	--	44.7	0	.26
17	Marine clay	15.0	118.0	33.6	360	.13
18	Marine clay	24.0	107.4	27.5	420	.10
19	Marine clay	30.4	98.1	27.1	420	.11
19	Marine clay	27.0	91.9	30.3	240	.15
20	Marine clay	33.0	96.9	33.2	180	.28
21	Mitkof	49.0	60.6	34.2	160	.35
22	Mitkof	32.0	72.4	35.2	240	.30
23	Kupreanof	21.2	98.1	44.4	0	.13
26	Kupreanof	84.5	51.5	36.6	180	.25
26	Kupreanof	--	--	36.0	300	.15
27	Mitkof	23.0	107.3	34.4	300	.01
28	Mitkof	16.2	--	26.6	740	.04
29	Mitkof	38.0	76.6	37.5	140	.27
30	Mitkof	76.0	51.3	25.6	300	.35
30	Mitkof	75.9	54.5	39.2	80	.33
31	Traitors (Vixen)	23.4	97.5	40.2	140	.32
32	Traitors (Vixen)	47.5	63.8	34.4	160	.36
33	Traitors (Vixen)	28.1	--	34.4	280	.22
34	Traitors (Vixen)	64.5	59.5	32.1	280	.32
35	Traitors (Vixen)	48.2	72.6	35.6	220	.19
36	Traitors (Vixen)	50.0	71.4	38.7	140	.25
37	Tolstoi	65.5	64.9	33.6	200	.24
38	Tolstoi	55.0	65.2	34.8	140	.41
39	Tolstoi	120.0	41.1	34.7	140	.49
40	Tolstoi	28.0	85.0	34.9	160	.29

** Two-stage test.

1/ Tentative Soil Conservation Service names.

Table 3—Samples grouped by Soil Resource Inventory (SRI) soil type

Soil series 1/	Site and sample number	Geologic origin
Karta	3,8	Glacial till
Shelikof	4	Weathered volcanic ash and pumice
Sitka	5	Weathered volcanic ash and pumice
Tokeen	6	Residual soil derived from graywacke
Ulloa	9	Residual soil derived from graywacke
Wadleigh	10,11,12,13,14,15,16	Weathered glacial till
Marine clay (Gunnuck)	7,17,18,19,20	Postglacial uplifted marine deposits, clay, and silts
Mitkof	21,22,27,28,30	Weathered granitic bedrock and glacial till (undifferentiated)
Kupreanof	1,23,24,25,26,29	Alluvium derived from estuarine sediments
Traitors (Vixen)	31,32,33,34,35	Glacial till derived from phyllite and schist
Tolstoi Taxadjunct	2,36,37,38,39,40	Colluvium derived from graywacke

1/ Tentative Soil Conservation Service names.

Table 4—Samples grouped by Unified Soil Classification (USC) soil type

Unified Soil Classification	Soils series 1/	Site number	Geologic orgin
GM	Tolstoi	2	Colluvium (graywacke)
GM	Wadleigh	13	Weathered glacial till (graywacke)
GM	Kupreanof	24	Alluvium (estuarine sediment)
GM	Tolstoi	36	Colluvium (graywacke)
GM	Tolstoi	37	Colluvium (graywacke)
GM	Tolstoi	39	Colluvium (graywacke)
GM	Tolstoi	40	Colluvium (graywacke)
GC	Wadleigh	14	Weathered glacial till (graywacke)
GC	Wadleigh	15	Weathered glacial till (graywacke)
GC	Wadleigh	15	Weathered glacial till (graywacke)
SM	Karta	3	Glacial till (graywacke, granite)
SM	Shelikof	4	Volcanic ash, pumice
SM	Sitka	5	Volcanic ash, pumice
SM	Karta	8	Glacial till (graywacke, granite)
SM	Ulloa	9	Residual soil (limestone)
SM	Wadleigh	10	Weathered glacial till (graywacke)
SM	Mitkof	21	Weathered granitic bedrock and glacial till (undifferentiated)
SM	Mitkof	22	Weathered granitic bedrock and glacial till (undifferentiated)
SM	Kupreanof	23	Alluvium (estuarine sediment)
SM	Mitkof	27	Weathered granitic bedrock and glacial till (undifferentiated)
SM	Mitkof	28	Weathered granitic bedrock and glacial till (undifferentiated)
SM	Kupreanof	29	Alluvium (estuarine sediment)
SM	Tolstoi	38	Colluvium (graywacke)
SC	Tokeen	6	Residual soil (graywacke)
SC	Wadleigh	11	Weathered glacial till (graywacke)
SC	Wadleigh	12	Weathered glacial till (graywacke)
ML	Marine clay	18	Postglacial uplifted marine deposits, clay, and silts
ML	Marine clay	20	Postglacial uplifted marine deposits, clay, and silts
ML	Traitors	31	Glacial till (phyllite/schist)
ML	Traitors	32	Glacial till (phyllite/schist)
ML	Traitors	33	Glacial till (phyllite/schist)
ML	Traitors	34	Glacial till (phyllite/schist)
ML	Traitors	35	Glacial till (phyllite/schist)
MH	Kupreanof	1	Alluvium (estuarine sediment)
MH	Kupreanof	25	Alluvium (estuarine sediment)
MH	Kupreanof	26	Alluvium (estuarine sediment)
MH	Mitkof	30	Weathered granitic bedrock and glacial till (undifferentiated)
CL-ML	Gunnuck	7	Marine sediment
CH	Marine clay	17	Postglacial uplifted marine deposits, clay, and silts
CH	Marine clay	17	Postglacial uplifted marine deposits, clay, and silts

1/ Tentative Soil Conservation Service names.

Table 5—Samples grouped by geologic origin

Geologic origin	Soil series 1/	Site number	Unified soil classification
Colluvium (graywacke)	Tolstoi	2	GM
Glacial till (graywacke, granite)	Karta	3	SM
Glacial till (graywacke, granite)	Karta	8	SM
Glacial till (graywacke)	Wadleigh	10	SM
Glacial till (graywacke)	Wadleigh	11	SM
Glacial till (graywacke)	Wadleigh	12	SM
Glacial till (graywacke)	Wadleigh	13	SM
Glacial till (graywacke)	Wadleigh	14	SM
Glacial till (graywacke)	Wadleigh	15	SM
Glacial till (graywacke)	Wadleigh	16	SM
Weathered granitic bedrock and glacial till (undifferentiated)	Mitkof	21	SM
Weathered granitic bedrock and glacial till (undifferentiated)	Mitkof	22	SM
Weathered granitic bedrock and glacial till (undifferentiated)	Mitkof	27	SM
Weathered granitic bedrock and glacial till (undifferentiated)	Mitkof	28	SM
Weathered granitic bedrock and glacial till (undifferentiated)	Mitkof	30	SM
Glacial till (phyllite/schist)	Traitors	31	ML
Glacial till (phyllite/schist)	Traitors	32	ML
Glacial till (phyllite/schist)	Traitors	33	ML
Glacial till (phyllite/schist)	Traitors	34	ML
Glacial till (phyllite/schist)	Traitors	35	ML
Colluvium (graywacke)	Tolstoi	36	GM
Colluvium (graywacke)	Tolstoi	37	GM
Colluvium (graywacke)	Tolstoi	38	SM
Colluvium (graywacke)	Tolstoi	39	GM
Colluvium (graywacke)	Tolstoi	40	GM
Marine sediment	Gunnuck	7	CL-ML
Postglacial uplifted marine deposits, clay and silts	Marine clay	17	CH
Postglacial uplifted marine deposits, clay and silts	Marine clay	18	ML
Postglacial uplifted marine deposits, clay and silts	Marine clay	19	CH
Postglacial uplifted marine deposits, clay and silts	Marine clay	20	ML
Alluvium (estuarine sediment)	Kupreanof	1	MH
Alluvium (estuarine sediment)	Kupreanof	23	SM
Alluvium (estuarine sediment)	Kupreanof	24	GM
Alluvium (estuarine sediment)	Kupreanof	25	MH
Alluvium (estuarine sediment)	Kupreanof	26	MH
Alluvium (estuarine sediment)	Kupreanof	29	SM
Volcanic ash, pumice	Shelikof	4	SM
Volcanic ash, pumice	Sitka	5	SM
Residual soil (graywacke)	Tokeen	6	SC
Residual soil (graywacke)	Ulloa	9	SM

1/ Tentative Soil Conservation Service names.

Table 6—Estimated range of engineering properties for Soil Resource Inventory (SRI) soil types 1/

Soil series	Mean ϕ'	Fifth percentile ϕ'	Mean c'	Fifth percentile c'	Mean γ
	- - - degrees - - -		- - - lb/ft^2 - - - -		lb/ft^3
Karta	36	23	146	88	122
Shelikof	25	*	230	*	83
Sitka	39	*	250	*	84
Tokeen	36	*	104	*	103
Ulloa	34	*	125	*	102
Wadleigh	37	27	181	0	119
Marine clay	33	20	312	108	131
Mitkof	33	22	303	0	102
Kupreanof	38	31	182	0	109
Traitors	36	30	203	71	105
Tolstoi	36	29	149	79	111

* = one sample only; mean value is result of single test.

1/ Mean values should be used for general assessment of soil behavior. Fifth percentile values should be used for conservative analysis of sensitive areas.

Table 7—Estimated range of engineering properties for Unified Soil Classification (USC) soil types 1/

Unified Soil Classification	Mean ϕ'	Fifth percentile ϕ'	Mean c'	Fifth percentile c'	Mean γ
	- - - degrees - - -		- - - - lb/ft^2 - - - -		lb/ft^3
GM	37	29	157	83	114
CG	39	24	180	0	122
SM	35	25	209	0	110
SC	36	29	182	0	126
ML	34	27	228	35	114
MH	35	24	230	34	93
CL-ML	44	*	250	*	138
CH	30	24	340	157	127

* = one sample only; mean value is result of single test.

1/ Mean values should be used for general assessment of soil behavior. Fifth percentile values should be used for conservative analysis of sensitive areas.

Table 8—Estimated range of engineering properties for geologic materials [1]

Geologic origin	Mean ϕ'	Fifth percentile ϕ'	Mean c'	Fifth percentile c'	Mean γ
	- - -degrees - - -		- - - lb/ft^2 - - -		lb/ft^3
Colluvium and till soils	36	27	206	0	116
Marine clays	33	20	312	0	131
Alluvium	38	31	182	0	109
Volcanic ash	32	12	240	210	82
Residual soils	35	33	115	85	102

[1] Mean values should be used for general assessment of soil behavior. Fifth percentile values should be used for conservative analysis of sensitive areas.

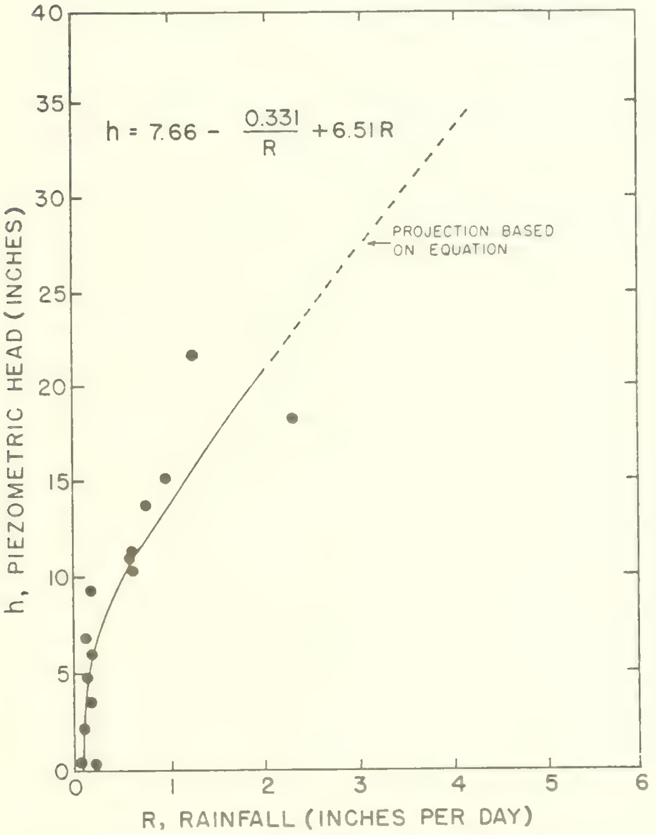

Figure 2—Response of the water table to rainfall intensity within shallow upslope depressions at Hollis, Prince of Wales Island. The soil in the depressions belongs to the Karta series (SM) (Adapted from Swanston 1967.)

Landslide Risk Analysis Procedures

Prellwitz (1985) recommends a three-level approach to landslide risk analysis. Each successive level requires a more detailed look at the potential for mass instability. Briefly described, Prellwitz' recommended analysis levels include the following:

Level I—Resource allocation; provides managers with an overview of landslide potential that is adequate for resource allocation planning.

Level II—Project planning; predicts response of slide-prone areas to various harvesting systems and transportation routes.

Level III—Critical site stabilization; evaluates stabilization techniques at critical sites before and after any construction.

Figure 3 gives a general outline for any landslide risk assessment. Elements of it can be incorporated in either a level I or a level II analysis; either analysis requires topographic mapping and geologic reconnaissance studies. The geologic reconnaissance study identifies bedrock and structural control in an area, defines limiting characteristics of terrain and materials, and delineates areas where mass movement historically has been a problem. In level I studies, these areas usually are designated as "high-risk zones" and are avoided in resource allocation plans or are identified for more intensive evaluation. Soil properties usually are not quantified nor are engineering analyses made. Risk assessment is based largely on an inductive evaluation of the area, which is based on observation. In level II studies, more specific site investigations are incorporated to identify critical zones of instability and to provide a way to determine where cutting units and roads will be located.

The engineering methods presented here supplement the experience-based assessment procedures commonly used for resource allocation planning. The methods provide an analytical approach to identify a range of risk levels within a potentially troublesome area and to assign criteria for efficient and effective management.

Required Data

Data required to use the objective analysis method include:

1. Slope data—natural slope angle and the slope angle and height of the road cut. These are obtained from topographic maps, field measurements, and preliminary construction plans.

2. Ground-water levels—location of the ground-water surface during critical periods. In southeast Alaska this is usually between September and December. Swanston's (1967) analysis of ground-water fluctuations in response to 24-hour rainfall intensities for shallow, permeable soils is shown in figure 2. To use figure 2, it is necessary to determine, for the location of landslide risk assessment, a rainfall associated with the project requirements. Isohyte maps of 24-hour rainfall intensity for different recurrence intervals in southeast Alaska were plotted by Miller (1963). An example for a 10-year recurrence interval is shown in figure 4.

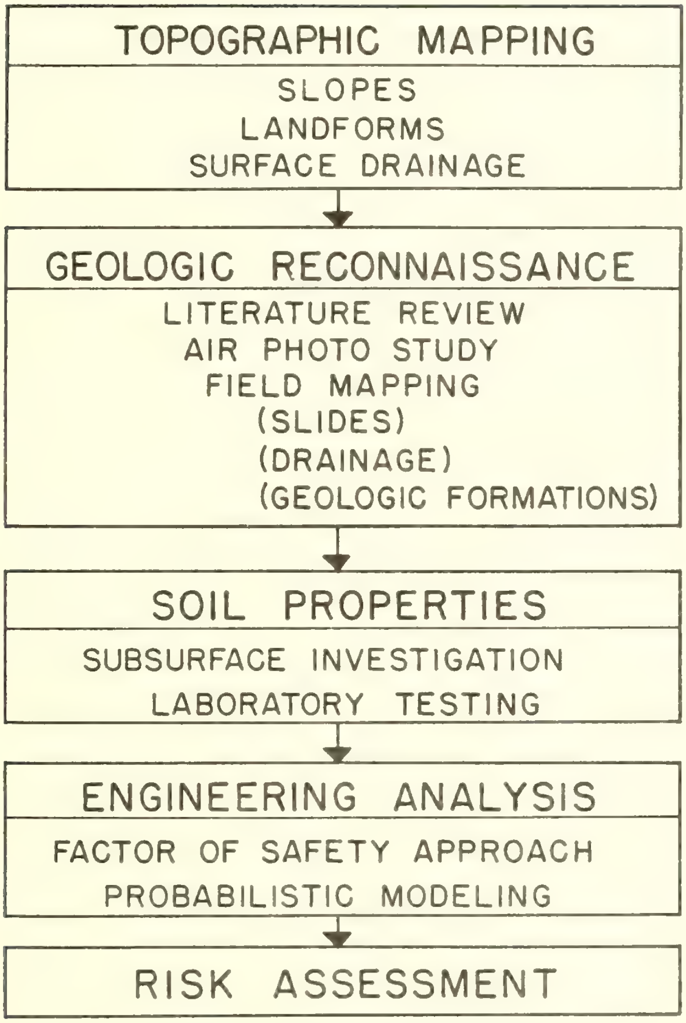

Figure 3—General outline for landslide risk assessment at the resource allocation (I) and project planning (II) levels. Topographic mapping and geological reconnaissance are required for both levels. In addition, level II requires more specific soil properties investigation and engineering analysis to identify critical zones of instability and a range of risk levels.

Judgments must be made on the appropriate recurrence period when a rainfall intensity is selected for analysis. The appropriate period might be based on the estimated time of establishment of new vegetation at a clearcut site, the estimated time for maximum decay of old-growth root systems following cutting, or the design-life of a road. There is some guidance for making these judgments. Wu and Swanston (1980) show that maximum instability of a steep site due to decay of old-growth spruce-hemlock systems *(Picea* sp.-*Tsuga* sp.) occurs about 4 years after clearcutting. Significant regrowth of stabilizing vegetation occurs in about 8 years. Storms with intensities great enough to produce a maximum rise in the water table within the period of minimum stability will result in high-risk situations. Storms with recurrence intervals greater than the period of significant regrowth will have a much lower potential for producing landslides.

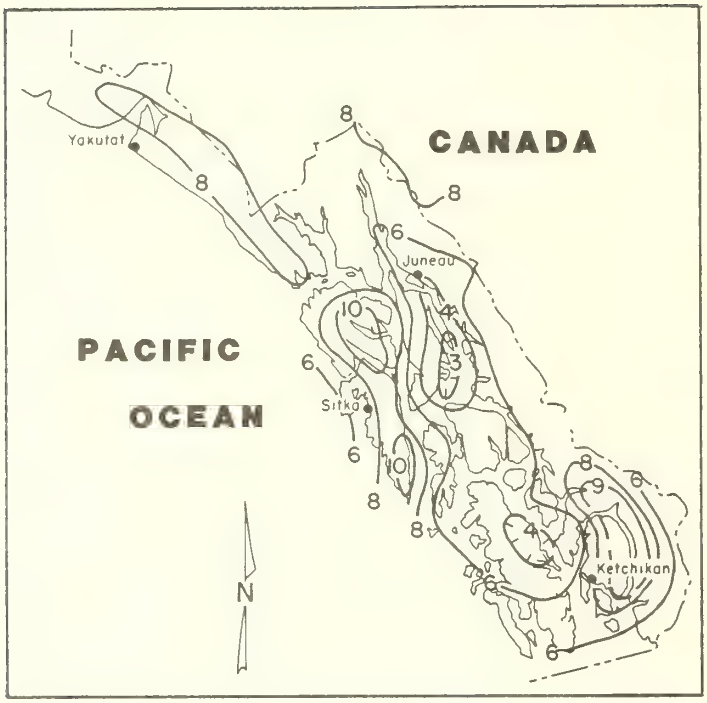

Figure 4—Ten-year recurrence interval, 24-hour rainfall pattern for southeast Alaska, in inches (Miller 1963).

The piezometric head on the y-axis of figure 2 is the water level above an impervious subsurface. Soil depth above this impervious surface must also be known to do a stability analysis. In the typically shallow soils found at unstable sites in southeast Alaska, soil depth can be obtained readily by using probes or augers. For deeper soil sites or where large quantities of rock are entrained in the overburden profile, a seismograph can be used. For level I (planning) analyses, estimates of soil depth based on Soil Resource Inventory (SRI) maps are usually adequate.

3. Data on soil properties are summarized in tables 6, 7, and 8. Any of these tables can be used to assign soil properties for analysis according to terrain information available to the user. In the tables, mean soil shear strength variables (ϕ') and (c'), and bulk (saturated) unit weights (γ) are given. Also shown are more conservative (fifth percentile) values of the shear strength parameters. The minimum values are derived by subtracting two standard deviations from the mean parameter to obtain an approximate lower 95-percent confidence limit. By this method, the parameter indicated represents, approximately, the lower strength limit for 95 percent of the soil group. The accuracy of these lower limits can be only approximated because of the small number of samples in each soil group. Where better data are available, or where individual sites have been identified for further project level analysis, the user should develop and assign more appropriate soil strength parameters. In level II site investigations, particular care should be taken when directly applying these assigned values. Natural variation in soil properties and structural weaknesses (for example, the presence of a weak layer at the soil/rock interface) may result in overestimation of material strength.

Analysis

This section explains the recommended procedures for level I or level II analysis (refer to fig. 3). A geologic reconnaissance is desirable at both levels to define controlling terrain characteristics and to identify those areas with a history of active landsliding. In addition, site investigations should be conducted in identified critical areas for level II to facilitate location of final cutting unit boundaries and road corridors. The investigations should include, at a minimum, preparation of field-developed cross sections and collection of data on site-specific soil properties and structure. Step-by-step procedures are:

1. Obtain a topographic map of the study area.

2. Prepare an overlay map of the slopes in the study area using convenient slope ranges; suggested ranges are 0-30 percent, 30-50 percent, 50-60 percent, and more than 60 percent.

3. Identify areas with a history of active landsliding by using aerial photographs, ground reconnaissance, or available landslide inventories.

4. Identify dominant soil types and depths for each portion of the study area within each slope range selected in step 2. Choose strength parameters, ϕ', and c', and a bulk unit weight, γ, from tables 1, 2, or 3. Mean values normally are used, but minimum values may be chosen for especially sensitive areas.

5. Select the recurrence interval for the 24-hour rainfall to be used in the stability assessment. Research has shown that landslide frequency is greatest in clearcuttings 3 to 5 years after logging (Swanston 1974). Conservative estimates of landslide risk could, therefore, be based on a 10-year recurrence interval; less conservative estimates could be based on a 5-year return interval.

6. Determine, from figure 2, the estimated ground-water height (piezometric head), h, for the selected 24-hour rainfall.

7. Use simplified engineering procedures and estimated or field-developed strength parameters to determine the potential instability of natural slopes and slopes created by cuts for roads.

Natural slopes—Use equation (2), the infinite slope equation, to compute the factor of safety (FS) for various slope classes:

$$FS = \frac{c'}{\gamma z \cos\beta\sin\beta} + \frac{\gamma - m\gamma_w}{\gamma}\,\frac{\tan\phi'}{\tan\beta}\,. \qquad (2)$$

In equation (2), c', ϕ', and γ are taken from tables 6, 7, or 8. The soil depth is z. If h is the ground-water height from step 6, above, then m = h/z. The unit weight of water, γ_w, is 62.4 pounds per cubic foot (lb/ft^3). Other units may be used in equation (2), but all units must be dimensionally consistent. Slope angle, in degrees, is represented by β, which is equal to the angle whose tangent is the percent of the slope divided by 100.

Cut slopes—Slopes caused by cuts made for roads are presumed to be stable at the time of excavation. In special cases, where previously existing landslides are transected by a cut, this would not necessarily be true. For purposes of risk analysis, such areas would be identified in the geologic reconnaissance phase and be assessed separately. Typically, cut slopes become unstable during the rainy season.

In addition to steps 1-6, above, it is necessary to know the proposed angle (β) of the cut slope and the slope height to compute the relative stability of proposed cut slopes. For logging roads, a proposed cut slope angle is estimated and height limits for the slope are chosen based on roadway width requirements, road alignment, and topography.

For cohesionless soils ($c' = 0$), the factor of safety is computed using equation (2). The first term is set equal to zero and β is set equal to the angle of the cut slope above the horizontal. For cohesive soils, calculations are based on the method illustrated in figure 5.

Examples—Suppose the impact on slope stability from roads and from logging a watershed in the upper elevations of northern Chichagof Island must be estimated. A geologic reconnaissance of the watershed has been completed by using aerial photographs and limited ground reconnaissance. There are no significant bedrock exposures. The dominant soil type is a weathered glacial till with an average depth of 6 feet. The overlay map of the slopes has been completed, and it shows the following distribution of natural slope classes:

Slope class	Slope angle	Percent of watershed area
0-30 percent	0-16.7°	26
30-50 percent	16.7-26.6°	52
50-60 percent	26.6-31°	18
>60 percent	>31°	4

From table 8, the following soil properties are selected:

ϕ' (mean) = 36°
c' (mean) = 206 pounds per square foot (lb/ft^2)
γ (mean) = 116 pounds per cubic foot (lb/ft^3)
ϕ' (minimum) = 27°
c' (minimum) = 0 pounds per square foot (lb/ft^2)

For a 10-year recurrence interval, the estimated 24-hour rainfall is 10 inches (from fig. 4). From figure 2, for a projection of 10 inches of rainfall per day in drainage depressions, h = 73 inches or about 6 feet. Therefore m = 1. For natural slopes and under average conditions, from equation (2):

$$FS = \frac{206}{116(6)\cos\beta\sin\beta} + \frac{116 - 1(62.4)}{116}\left[\frac{\tan(36)}{\tan\beta}\right]$$

$$= \frac{0.296}{\sin\beta\cos\beta} + \frac{0.336}{\tan\beta}$$

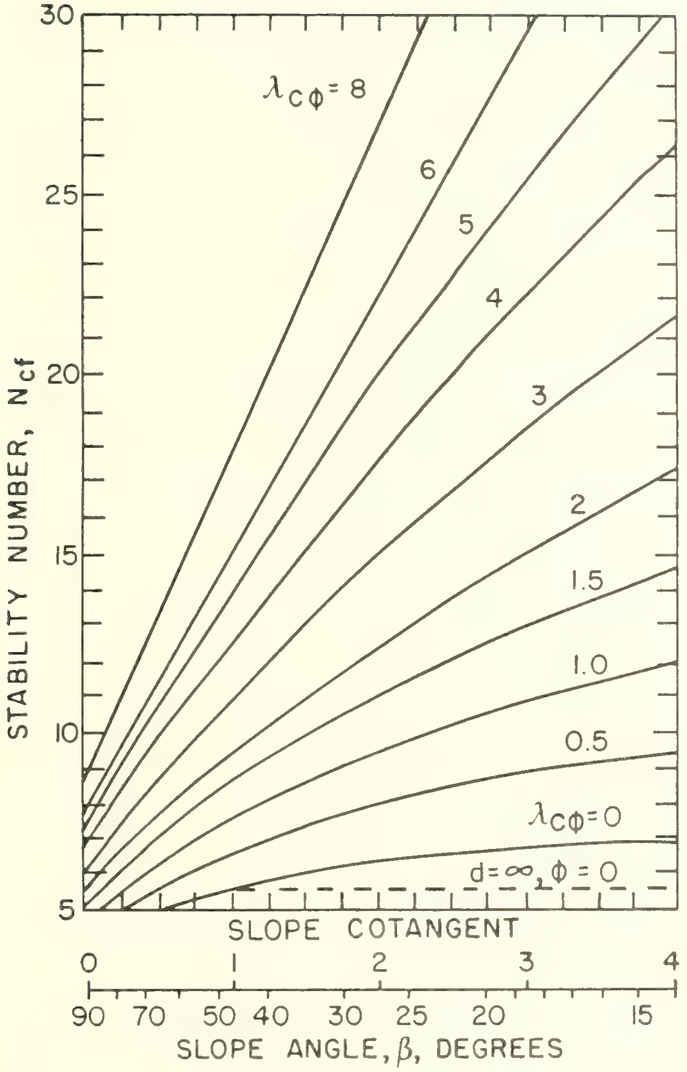

Figure 5—The relation between the angle of the cut slope (β) and stability number (N_{cf}) for different seepage factors ($\lambda_{c\phi}$), in cohesive soils. If ground water flow is present, use an approximation of the angle of internal friction, $\phi = \phi' \left[\frac{\gamma - m\gamma_w}{\gamma}\right]$, to define the seepage factor, $\lambda_{c\phi} = \frac{\gamma H \tan\phi}{c}$. The stability number, N_{cf}, can then be taken from the chart. The factor of safety is $= \frac{N_{cf}c}{\gamma H}$.

Combining Reconnaissance and Analysis

For the various slope classes, the range in the factor of safety (FS) would be:

Slope class	Percent of watershed area	FS
0-30 percent	26	Very high-2.20
30-50 percent	52	2.20-1.41
50-60 percent	18	1.41-1.23
>60 percent	4	<1.23

Now consider the proposed roads in the watershed. Preliminary plans indicate that the cuts for roads will be as high as 15 feet and that the slope inclination will be 1/2 (horizontal):1 (vertical). Previously selected soil properties are applicable, as is the water level resulting from rainfall infiltration for the 10-year, 24-hour rainfall.

First, β = arc tan (2) = 63.4°. Because of the heavy downslope seepage, an approximation must be made for ϕ to use figure 5:

$$\phi = \phi' \left[\frac{\gamma - m\gamma_w}{\gamma}\right] = 36 \left[\frac{116 - (1)62.4}{116}\right] = 16.6^\circ \; ; \tag{3}$$

which leads to:

$$\lambda_{c\phi} = \frac{\gamma H \tan\phi}{c} = \frac{116(6)\ \tan(16.6)}{206} = 1.01 \; . \tag{4}$$

Note that the soil depth, z, is less than the full depth of the cut. Therefore, the cut height, H, is equal to z, or 6 feet. Then from figure 5, N_{cf} = 6.3 and:

$$FS = \frac{N_{cf}c}{\gamma H} = \frac{6.3(206)}{116(6)} = 1.86 \; . \tag{5}$$

The result indicates that the soil mantle over rock in the deepest proposed cuts would be stable (FS >1) and would have an adequate (>1.5) factor of safety.

The areas with greatest landslide risk are those where landslides have happened before, where analysis indicates they should happen again, and where there will be unacceptable consequences if they do happen. The areas with least risk are those where there have been no slides, where analysis shows that there should not have been slides, and where the consequences would be tolerable if there were slides. In between these limits there is a gradation of risk that can be assigned according to criteria listed in table 9.

The descriptions "low," "moderate," and "high" are subjective only. Risk levels can also be quantified based on probability. To do so requires a large data base to determine confidence in parameters for soil shear strength and in ground-water response to rainfall. Because this data base is not presently available for southeast Alaska, we did not quantify risk based on probability.

Table 9—Supplemental criteria for assessing the risk of landslides

Landslide history	Factor of safety	Consequences	Relative risk
None	> 1.50	Tolerable	Low
Limited	1.25-1.50	Excessive	Moderate
Frequent	< 1.25	Unacceptable	High

To use table 9, begin with the landslide history and use data from ground reconnaissance or aerial photographs. If the area under consideration has frequent landslides or is presently involved in active sliding, if the calculated factor of safety is less than 1.25, and if a new slide would produce unacceptable consequences, the area is a high-risk area. It should be avoided, or the risks should be reduced in some way. For other, less well-defined situations, judgments must be made concerning weights to be assigned to each criterion in table 9 to arrive at an overall risk level. For instance, in an area with no landslide history (low risk), where the calculated factor of safety is 1.3 (moderate risk), and where the consequences of an actual slide are tolerable (low risk), an activity capable of triggering a slide could probably be done without great risk.

In our hypothetical watershed on Chichagof Island, there was no notable landslide history and no especially sensitive areas to be affected by landslides. The stability analysis for natural slopes indicates, according to table 9, that clearcutting on slopes up to about 50 percent would be generally acceptable and should not produce significant sliding in the cut units. The risk goes up as slopes approach 60 percent but is still generally acceptable. Slopes steeper than 60 percent should not be logged. The analysis therefore indicates, based on slope stability risks, that up to 96 percent of the watershed may be cut. The leave areas should be shown on the overlay map. Slopes adjacent to proposed roads in the watershed should be stable. The analysis cannot be interpreted to mean that there would be no slides in the cut units and along roads because all slide-susceptible areas, of course, may not be adequately represented in the data base.

Road Subgrades and Bases

Costs for timber access and haul roads in southeast Alaska vary dramatically according to the suitability of onsite materials for roadway construction. Most road building in the Alaska Region (of the USDA Forest Service) requires development of offsite quarries, and transport costs can be very high. Quarry development may result in a major environmental impact. Where materials from within the road alignment can be used for construction, both dollar savings and aesthetic benefits result. In a few areas, depending on joint spacing and construction methods, excavations can be used for fill. Unfortunately, on steep ground it is difficult to blast rock small enough for fill and to keep it at the site.

Surfacing for roads requires good quality material. In southeast Alaska surfacing usually comes from natural materials that most often consist of pit run, screened, or crushed quarry rock. Asphalt and concrete surfacing are seldom used. The required thickness of rock varies according to the strength of the underlying subgrade materials. Conditions throughout southeast Alaska are generally poor for road construction. The wet climate, the predominance of soils with considerable fines content, and the standard practices currently followed by the road building industry result in circumstances that make quality road construction difficult, at best. Rather than building conventional roads on compacted subgrades with thin layers of base materials (less than 16 inches), subgrade reinforcement to depths ranging from 2 to 10 feet is needed to support vehicles.

Tables 1 and 4 provide Unified Soil Classification (USC) designations for soils represented in the data base. Table 4 relates these classes to both soil series and geologic origin. The classes of soils to be expected in a given management area can be forecast from geology and soil survey maps.

Table 10 ranks soils for road construction purposes according to their Unified Soil Classification designation; the ranking runs from highest quality to lowest. Table 4 is arranged the same way. Base course-type materials usually serve as the road surface.

It is beyond the scope of this paper to provide design criteria for surface thickness of Forest Service roads. Such designs are more properly handled by regional or area engineering staffs. However, this section provides the basis for a general assessment of the suitability of natural materials for road construction. Such an assessment is consistent with the level of definition provided by landslide risk analysis at level I or level II (Prellwitz 1984).

Consider, for example, the hypothetical watershed on northern Chichagof Island that was discussed earlier. The area is underlain predominantly by weathered glacial tills. Table 4 shows that these are typically coarse soils, usually gravels, with considerable plastic fines. Table 1 indicates that fines content might range between about 20 and 50 percent.

Table 10 shows that weathered glacial tills would be good subgrade materials, even if subject to frost action, but they contain too much fine material to be suitable for a base course beneath a paved surface or a wearing surface. Further, the high fines content does not allow good drainage and, in the climate of southeast Alaska, probably makes such soils difficult to compact and to work with equipment during most of the year. A road constructed on these materials would require an imported surfacing.

The foregoing example considers the expected suitability of onsite road building materials in one of the higher quality (upper portion of table 4) materials in the data base. The evaluation indicates that properly placed and compacted, the material is good as a subgrade; however, actual field conditions are likely to work against good construction practices. Timber access and haul road construction in southeast Alaska usually will be difficult and expensive because other materials are of typically lower quality.

Table 10—Suitability of natural materials for road construction

	Value when material not subject to frost action							Typical design values	
USC 1/ symbol and description	As subgrade	As subbase	As base	Potential frost action	Drainage characteristics	Compaction equipment 2/	Unit 3/ dry weight	CBR 4/	Subgrade modulus k 5/
							lb/ft^3		lb/ft^3
Coarse-grained soils (gravel and gravelly soils):									
GW, well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent	Good	None to very slight	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125-140	40-80	300-500
GP, poorly graded gravels or gravel-sand mixtures little or no fines	Good to excellent	Good	Fair to good	None to very slight	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110-140	30-60	300-500
GMd, silty gravels, gravel-sand-silt mixtures	Good to excellent	Good	Fair to good	Slight to medium	Fair	Rubber-tired roller, sheepsfoot roller; close control of moisture	125-145	40-60	300-500
GMu, silty gravels, gravel-sand-silt mixtures	Good	Fair	Poor to not suitable	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	115-135	20-30	200-500
GC, clayey gravels, gravel-sand-clay mixtures	Good	Fair	Poor to not suitable	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	130-145	20-40	200-500
Coarse-grained soils (sand and sandy soils):									
SW, well-graded sands or gravelly sands, little or no fines	Good	Fair to good	Poor	None to very slight	Excellent	Crawler-type tractor, rubber-tired roller	110-130	20-40	200-400
SP, poorly graded sand or gravelly sands, little or no fines	Fair to good	Fair	Poor to not suitable	None to very slight	Excellent	Crawler-type tractor, rubber-tired roller	105-135	10-40	150-400
SMd, silty sands, sand-silt mixtures	Fair to good	Fair to good	Poor	Slight to high	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	120-135	15-40	150-400
SMu, silty sands, sand-silt mixtures	Fair	Poor to fair	Not suitable	Slight to high	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-130	10-20	100-300
SC, clayey sands, sand-clay mixtures	Poor to fair	Poor	Not suitable	Slight to high	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-135	5-20	100-300
Fine-grained soils (silts with liquid limit less than 50):									
ML, inorganic silts and very fine sands, rock flour silty or clayey fine sands or clayey silts with slight plasticity	Poor to fair	Not suitable	Not suitable	Medium to very high	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	90-130	15 or less	100-200
CL, inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Poor to fair	Not suitable	Not suitable	Medium to high	Practically impervious	Rubber-tired roller, sheepsfoot roller	90-105	5 or less	50-150
OL, organic silts and organic silt-clays of low plasticity	Poor	Not suitable	Not suitable	Medium to high	Poor	Rubber-tired roller, sheepsfoot roller	90-105	5 or less	50-100

See footnotes at end of table.

Table 10—Suitability of natural materials for road construction (continued)

USC 1/ symbol and description	Value when material not subject to frost action			Potential frost action	Drainage characteristics	Compaction equipment 2/	Unit 3/ dry weight	Typical design values	
	As subgrade	As subbase	As base					CBR 4/	Subgrade modulus k 5/
							lb/ft^3		lb/ft^2
Fine-grained soils (silts and clays with liquid limit greater than 50):									
MH, inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable	Not suitable	Medium to very high	Fair to poor	Sheepsfoot roller, rubber-tired roller	80-105	10 or less	50-100
CH, inorganic clays of high plasticity, fat clays	Poor	Not suitable	Not suitable	Medium	Practically impervious	Sheepsfoot roller, rubber-tired roller	90-115	15 or less	50-100
OH, organic clays of medium to high plasticity organic silts	Poor to very poor	Not suitable	Not suitable	Medium	Practically impervious	Sheepsfoot roller, rubber-tired roller	80-110	5 or less	25-100
Fine-grained soils (silts and clays with liquid limit greater than 50):									
Pt, peat and other highly organic soils	Not suitable	Not suitable	Not suitable	Slight	Fair to poor	Compaction not practical	--	--	--

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1/ Unified Soil Classification system. Divisions based on grain size and plasticity properties. Division of GM and SM groups into subdivisions, d and u, are for roads and airfields only. Subdivision is on basis of Atterberg Limits; suffix d (for example, GMd) will be used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u will be used otherwise.

2/ The equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.

a. *Processed base materials and other angular materials.* Steel-wheeled and rubber-tired rollers are recommended for hard, angular materials with limited fines or screenings. Rubber-tired equipment is recommended for softer materials subject to degradation.

b. *Finishing.* Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed materials.

c. *Equipment size.* The following sizes of equipment are necessary to assure high unit weights:

Crawler-type tractor--total weight in excess of 30,000 lb.

Rubber-tired equipment--wheel load in excess of 15,000 lb; wheel loads as high as 40,000 may be necessary to obtain the required unit weights for some materials (based on contact pressure of approximately 65 to 150 lb/in^2).

Sheepsfoot roller--unit pressure (on 6- to 12-in^2 foot) to be in excess of 250 lb/in^2 and unit pressures as high as 650 lb/in^2 may be necessary to obtain the required unit weights for some materials. The area of the feet should be at least 5 percent of the total peripheral area of the drum, using the diameter measured to the faces of the feet.

3/ Unit dry weights are for compacted soil at optimum moisture content for modified AASHO compaction effort.

4/ California Bearing Ratio. The maximum value that can be used in design of airfields is, in some cases, limited by gradation and plasticity requirements.

5/ Modulus of subgrade reaction.

Conclusions

Extensive quantification of geotechnical information on surficial materials in southeast Alaska is lacking. A data base is developing, however, that links engineering properties and index values to dominant soil types as designated and mapped by the USDA Forest Service, Alaska Region, Soils Resource Inventory. This information, coupled with simplified engineering analysis procedures, can be used in resource allocation and project planning analyses to determine the potential instability of natural slopes and of slopes created by cuts for roads. The information is also useful for assessing the suitability of these soils as road subgrades and bases.

Metric Equivalents

1 inch (in) = 2.54 centimeters (cm)
1 foot (ft) = 0.31 meter (m)
1 mile (mi) = 1.61 kilometers (km)
1 pound-mass (lb) = 0.45 kilogram mass
1 square inch (in^2) = 6.47 square centimeters (cm^2)
1 square foot (ft^2) = 0.09 square centimeter (cm^2)
1 cubic inch (in^3) = 16.39 cubic centimeters (cm^3)
1 cubic foot (ft^3) = 0.03 cubic meter (m^3)
1 pound-force (lbf) = 4.45 newtons (N)
1 pound-force per square inch (lbf/in^2) = 0.07 kilogram-force per square centimeter (kgf/cm^2)
1 pound-mass per cubic inch (lb/in^3) = 27680.0 kilograms-mass per square meter (kg/cm^3)
1 pound-force per square foot (lbf/ft^2) = 4.88 kilograms-force per square meter (kgf/m^2)
1 pound-mass per cubic foot (lb/ft^3) = 16.02 kilograms-mass per cubic meter (kg/m^3)

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Recent quantification of engineering properties and index values of dominant soil types in the Alexander Archipelago, southeast Alaska, have revealed consistent diagnostic characteristics useful to evaluating landslide risk and subgrade material stability before timber harvesting and low-volume road construction. Shear strength data are summarized and grouped by Soil Conservation Service soil series, by the Unified Soil Classification system, and by geologic origin. Such groupings allow the selection of strength parameters for slope and subgrade stability analyses based on existing knowledge of the terrain and on available inventory data. Parameters are expressed by mean and minimum values so that both average and conservative evaluations can be made, depending on management requirements. Engineering procedures were used to incorporate the parameters into planning and project-level investigations to identify areas of unstable terrain, to assess levels of landslide risk, and to define suitability of materials for road construction.

Keywords: Slope stability, subgrade stability, soil properties (physical), southeast Alaska, Alaska (southeast).

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Preliminary Logging Analysis System (PLANS): Overview

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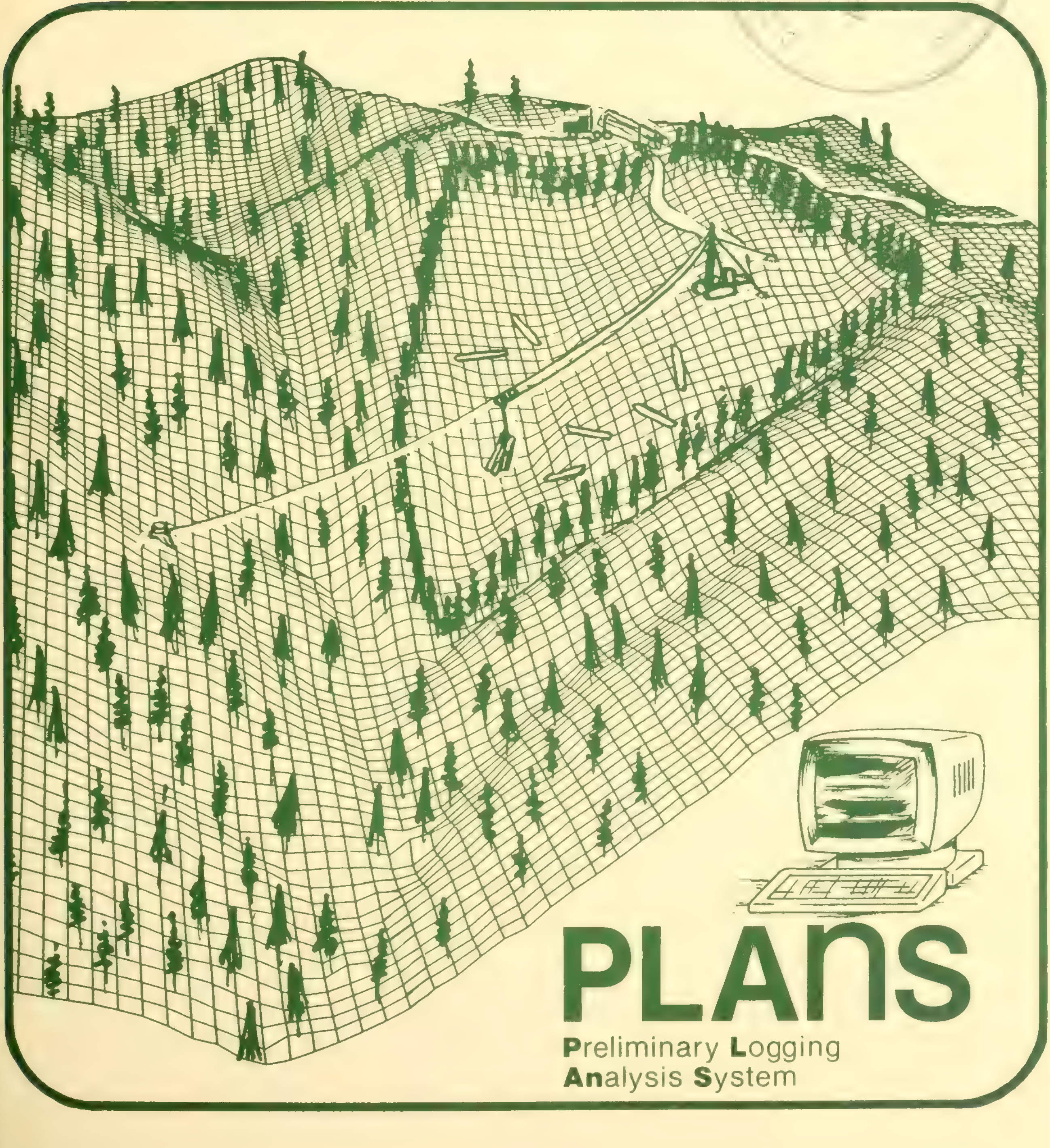

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Abstract

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The paper previews a computer-aided design system, PLANS, that is useful for developing timber harvest and road network plans on large-scale topographic maps. Earlier planning techniques are reviewed, and the advantages are explained of using advanced planning systems like PLANS. There is a brief summary of the input, output, and function of each program in the PLANS program set. The set presently includes programs for harvest unit design for a variety of cable logging systems, road locations, visual analyses, yarding costs, and slope attributes and a method for producing the elevation data files. Suggested ways to use PLANS to develop the harvest plans and to document and process harvesting alternatives are presented. Justifications are given for investments made in planning.

Keywords: Timber harvest planning, computer programs/programing, logging operations analysis/design, road building (forest/logging).

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Introduction

This report introduces a planning tool for expediting development of timber harvest plans. This tool, called PLANS (preliminary logging analysis system), is a family of computer programs that focuses on timber harvest planning. A major feature of PLANS is that it uses a stored digital terrain model, the equivalent of the planning area map, to supply the topographic data needed to design the timber harvest plan.

Good planning is vital to cable-log timber from steep terrain. The economic and environmental success of timber harvesting is strongly influenced by the cable yarding system selected for the operation and by how well the system is positioned on the terrain. Good positioning of the cable span permits hauling an ample volume of logs in each yarding cycle, which results in higher production and lower costs. Poor positioning results in excessive soil disturbance, hangups, reduced production, equipment breakdown, unsafe operations, or unworkable harvest units. The quality of timber harvest plans depends on the planner's thoroughness, which is influenced by time constraints, management support, and the planning tools provided.

The need for and the benefit of good planning has long been acknowledged by timber managers; however, defining what good planning is and institutionalizing it in an organization can be difficult. Planning has been mandated for the National Forest System by the Forest and Rangeland Renewable Resources Planning Act (1974) and the National Forest Management Act of 1976 (U.S. Laws, Statutes, etc. 1976). Jones and others (1986) compared four analytical approaches that are used to make National Forest land management and transportation planning decisions. They focused on a scale of planning termed "area-level-analysis" (ALA), and defined this as management units that are geographically contiguous land areas of 5,000 to 50,000 acres. Their examples, which illustrated various processes used in these four analyses, began at the point where the timber harvest units and transportation networks had already been identified and delineated. As a precursor to ALA, PLANS enables users to rapidly design and delineate timber harvest units and road access to timber for extensive areas. Area-level-analysis that begins with well-designed harvest units and transportation systems can proceed on a solid foundation. The individual timber harvest units and road alternatives form the foundation of the final management plan, and PLANS helps to ensure the operability and soundness of this foundation.

The scenario described above for ALA pertains to a specific and evolving planning environment in the National Forest System. Some basic considerations of timber harvest planning transcend the details of planning jurisdiction. One basic consideration is the influence of topography on the cost of timber harvesting. Topography affects most timber harvesting activities, from felling and yarding to road and landing construction; timber harvest planners therefore need detailed topographic information. This need has traditionally been met by topographic maps. Accurate maps with a scale of 1 inch to 1,000 feet, or larger, and contour intervals of 50 feet, or less, provide an excellent foundation for planning if used correctly. Planners can visualize steepness, ridges, valleys, benches, and profiles of the terrain from topographic maps. With maps and a knowledge of the operating requirements of various harvesting systems, planners can make good estimates as to where roads can be built, how much timber can be accessed by a given yarding system from a selected landing, and how best to fit a road and landing network together to provide a workable and complete timber harvest plan.

Review of Analytical Harvest Planning Methods

To assume that the planner's good judgment in choosing yarding span patterns from topographic maps is enough to ensure consistently adequate cable system payloads[1] is a high-risk and totally unsatisfactory practice. Planners can judge whether a cable yarding system will operate with a sufficient payload by mentally visualizing terrain shape while viewing a topographic map. They should confirm their judgment by calculating the potential payload, however, and this requires that a profile of each yarding corridor be carefully plotted. Before computers were used for planning, handbook procedures were used to determine payload. Potential skyline corridors were marked on a topographic map, and the terrain breaks (intersections of the corridor and the contour lines) were measured. The resulting profile was plotted, and its skyline payload was calculated using a chain and board simulation method (Lysons and Mann 1967). It took about 30 minutes to construct the profile and complete the payload analysis for a single skyline corridor. Related analyses of topographic profile data extracted from maps also made it possible to establish the locations for highlead units and logging roads (Pearce 1960). Timber harvest plans can be developed in this manner, although the time and effort absorbed generally limit their application.

The process of obtaining terrain profiles from topographic maps and of analyzing skyline system payloads improved when computer-based methods were introduced (Carson and others 1971). Programs based on computers interfacing with digitizers and plotters can now provide machine plotted profiles of digitized corridors. Other programs can calculate the resulting skyline payload for each profile. Only 5 minutes is needed to construct the profile and complete the payload analysis for a single skyline corridor.

The use of computers has made it convenient to quantitatively evaluate timber harvest plans, but the level of convenience provided by the programs is still inadequate to encourage the planner to thoroughly analyze full-rotation, total-area alternatives. The programs require considerable digitizing for each corridor examined, and hundreds of corridors must be examined for each alternative plan. Because of this, planners usually cannot analyze the full range of alternatives when developing full-rotation, total-area plans.

Harvest Planning With Digital Terrain Models

Burke (1974) suggests using a digital terrain model (DTM) for harvest planning. A DTM is an organized and comprehensive data file containing elevations that represent ground surface topography; the DTM is accessed directly by the computer. The advantage of the DTM concept is that it provides instant access to the numerous terrain profiles that should be analyzed when a total area harvest plan is developed.

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[1] The maximum weight of logs that can be safely transported to the landing in a single yarding cycle.

Young and Lemkow (1976) present a prototype timber harvest planning system that uses a digital terrain model. Their planning programs were based on a computer system[2] that, by present standards, is obsolete and inadequate for computer-aided design of logging units, though it was a state-of-the-art, interactive, desk-top computer system in 1976. Improvements in computer equipment and an increased awareness of the economic benefits of computer-aided design methods have resulted in expanded and improved planning systems that use digital terrain data. Reimer (1979) reports that an operational harvest planning system using digital terrain models was successfully implemented by McMillan Bloedel, Ltd., in Canada. Twito and Mifflin (1982) distributed[3] a preliminary version of PLANS that, like Reimer's planning system, operated on a Hewlett-Packard 9845 computer system.[4] Reutebuch and Evison (1984) report that an operational package using digital terrain models for cable system layout is available in New Zealand.

Description of PLANS

PLANS is a set of computer programs designed to assist logging engineers and transportation planners in developing timber harvest plans. PLANS allows the planner, aided by an interactive graphics computer system, to examine a wide range of design and planning options—a range not possible with earlier planning methods. PLANS, although it does not fully automate the design process, enhances the planner's ability to develop alternative timber harvest plans.

An earlier version of PLANS, which ran on the Hewlett-Packard 9845 computer (Twito and Mifflin 1982), has been enhanced and implemented on the Hewlett-Packard 9020 computer, which has greater operational convenience and faster computing speeds. New programs have also been added to PLANS. By using the PLANS package, the planner can construct and analyze the profile of a skyline corridor in less than 30 seconds. Other related PLANS design routines determine the maximum reach of cable yarding systems for profiles of circular settings in 2 seconds; only the planimetric results are displayed. Such routines, which depend on digital terrain model data, could not be done in a continuous-flow process with earlier planning methods.

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[2] A Hewlett-Packard 9830 desk-top computer system with no graphics screen, 16K bytes of random access memory, and an 8-bit processor.

[3] PLANS was distributed for testing within the USDA Forest Service and to a number of interested industrial forestry corporations that had compatible computer hardware.

[4] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Required Computer Hardware

PLANS was developed for a microcomputer-based, interactive graphics system with the following components:

1. Hewlett-Packard 9020B microcomputer with 1 megabyte of core memory and BASIC operating system,
2. Hewlett-Packard 7908P with 16.5-megabyte disk drive,
3. Hewlett-Packard 2932A dot-matrix printer,
4. Hewlett-Packard 7580B eight-pen drum plotter, and
5. CalComp 9480 36- by 48-inch digitizer with 12-button cursor.

An operational version of PLANS has also been translated to the Hewlett-Packard 9836 computer by the State of Washington.[5] Most interactive graphics computer systems can support a package similar to PLANS; however, converting the package to another system or language may require considerable effort.

Program Descriptions

Each program in PLANS will be documented in a separate technical report. Each technical report will include an analytical description of the program and a users guide. The following are brief descriptions of the programs presently available in PLANS.

The MAP program—The MAP program is used to produce digital terrain models with a grid pattern. These models are the source of terrain data for the other PLANS programs. Digital terrain models are produced by manually tracing contour lines from a topographic map mounted on the digitizer. Digitized contour data are converted by the program to an elevation matrix in grid form and are stored for later use. Large planning areas can be divided into smaller units for purposes of inputting data. Through this technique, digital terrain models of map areas larger than the digitizer can be built. An experienced user should be able to digitize 170 acres per hour when using topographic maps at a scale of 1 inch to 400 feet with 20-foot contours. This rate will vary with the map scale, the contour interval, and the complexity of the topography.

The SKYMOBILE and SKYTOWER programs—The SKYMOBILE and SKYTOWER programs analyze the load carrying capacity of skyline yarding systems. Terrain profiles of skyline corridors are obtained from a digital terrain model of the planning area. The SKYMOBILE program is used to analyze individual profiles and is best suited for planning harvest areas where the yarder is moved with each corridor change. The SKYTOWER program is used to analyze settings that will be yarded in a fan-shaped pattern to a central landing.

When the SKYMOBILE program is used, the planner designates a skyline profile for analysis by digitizing its beginning and ending points on the topographic map. The program extracts and displays the profile from the digital terrain model, and the planner chooses a yarder location from the profile. The program can then either determine the maximum span a specified payload can be yarded over, or it can determine the maximum payload that can be yarded over a specified span. SKYMOBILE simplifies the positioning of midslope roads by permitting analysis of several non-overlapping skyline spans on the same profile (fig. 1).

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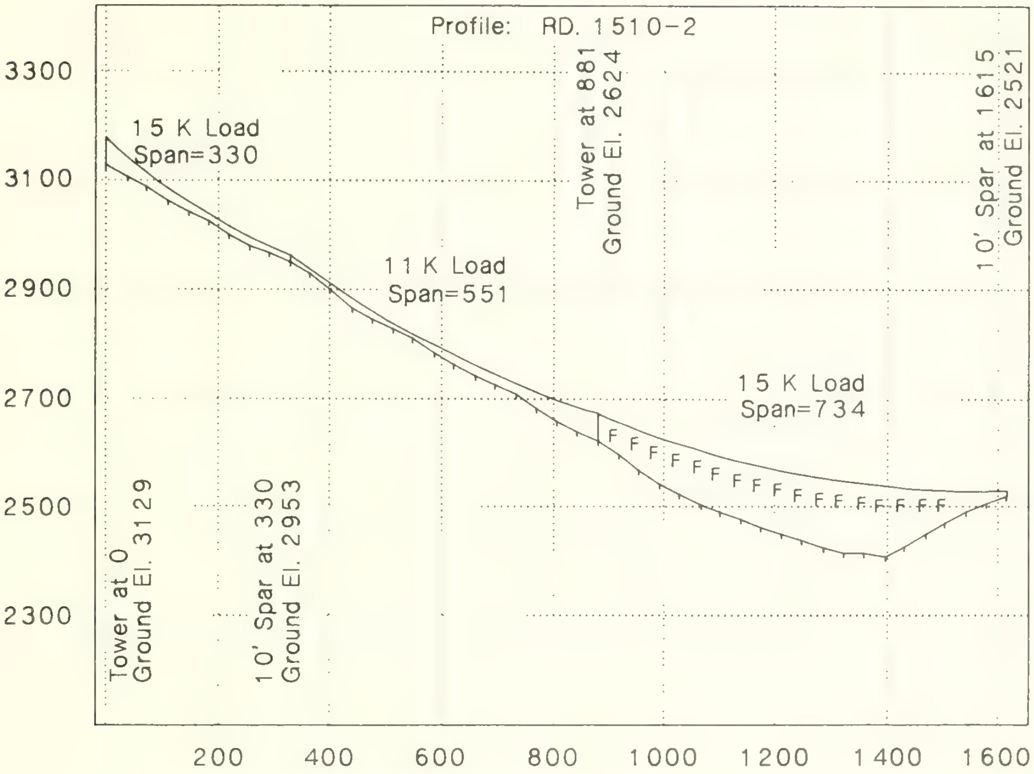
[5] Accomplished by the Department of Natural Resources, Olympia, in cooperation with the College of Forestry, University of Washington, Seattle.



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F--INDICATES FULL SUSPENSION OF THE LOAD

RUNNING SKYLINE SYSTEM SPECS:

    HAULBACK CABLE UNIT WEIGHT                                  1.42 LB/FT
    HAULBACK CABLE WORKING TENSION                             26500 LB
    COMBINED UNIT WEIGHTS OF MAIN & SLACKPULLING CABLES         2.84 LB/FT
    COMBINED WEIGHT OF CARRIAGE AND BUTT RIGGING                 500 LB
    TOWER HEIGHT                                                  50 FT
    TAILHOLD HEIGHT                                               10 FT
    CARRIAGE GROUND CLEARANCE                                     10 FT
    CARRIAGE HEIGHT FOR FULL SUSPENSION                           50 FT
    MAXIMUM SLOPE RIGGING DISTANCE                              1500 FT
    TARGET DRAGGING PAYLOAD                                    15000 LB

NOTE:  PAYLOADS WERE NOT COMPUTED WITHIN 50 FEET OF THE TAILHOLD.
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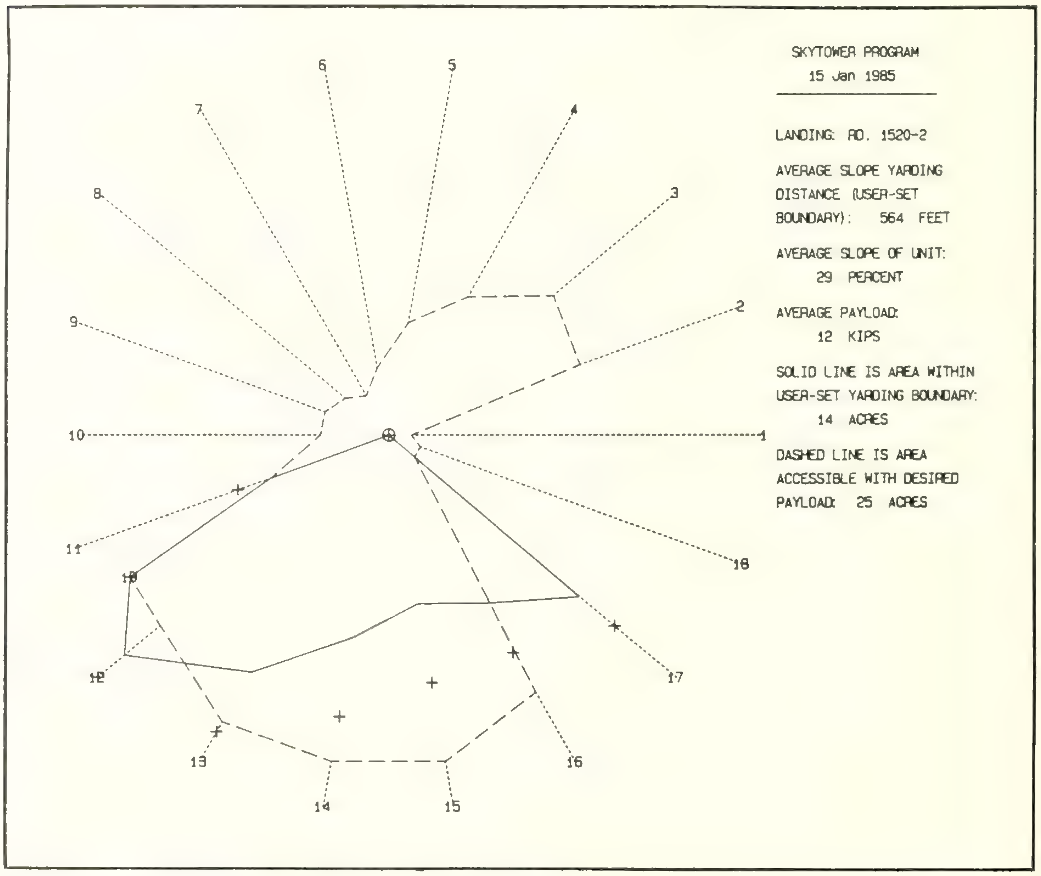
Figure 1—The skyline corridor profile plot and load path analysis as produced by the SKYMOBILE program.

When the SKYTOWER program is used, the planner designates a central landing by digitizing the yarder's location on the topographic map. The program automatically extracts 18 evenly spaced profiles radiating out from the landing. Each profile is analyzed to determine the maximum span a target load can be yarded over. A planimetric plot of the area that can be yarded to the landing is displayed. The planner can modify the boundary of this area by adding or deleting yarding corridors. Individual corridors can also be reanalyzed after the yarding system criteria have been altered. When a satisfactory unit design is complete, a planimetric overlay can be produced on the plotter (fig. 2) to simplify transfer of the harvest unit to the timber harvest plan.



SKYTOWER PROGRAM
15 Jan 1985

LANDING: RD. 1520-2

AVERAGE SLOPE YARDING
DISTANCE (USER-SET
BOUNDARY): 564 FEET

AVERAGE SLOPE OF UNIT:
29 PERCENT

AVERAGE PAYLOAD:
12 KIPS

SOLID LINE IS AREA WITHIN
USER-SET YARDING BOUNDARY:
14 ACRES

DASHED LINE IS AREA
ACCESSIBLE WITH DESIRED
PAYLOAD: 25 ACRES

Figure 2—The planimetric plot of the setting boundary as produced by the SKYTOWER program.

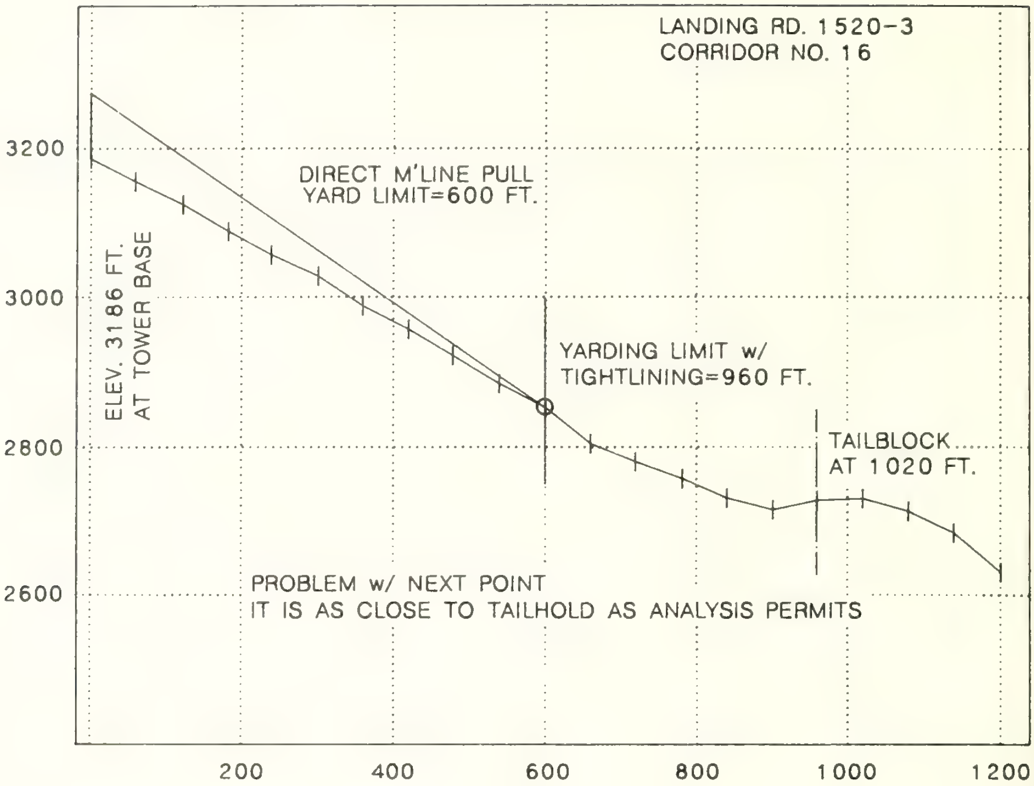
The HIGHLEAD program—The HIGHLEAD program analyzes highlead settings yarded in a fan-shaped pattern to a central landing. Like SKYTOWER, the HIGHLEAD program automatically analyzes 18 profiles radiating from a digitized yarder location. For each individual profile, the yarding limit is established either by the first instance of blind lead along the profile or by the maximum reach of the yarder. A plan of the area that can be yarded to the landing is displayed. The planner can attempt to increase the area of the setting by extending the yarding distance through tight-lining (tensioning the haulback line to increase lift and permit yarding beyond a point of blind lead). Figure 3 is an example of a corridor in which the yarding limit has been extended by tight-lining. The planner can also reduce the area of the setting by reducing yarding limits of individual corridors or by removing corridors from the setting. When a satisfactory setting design has been completed, a planimetric overlay can be produced on the plotter (similar to fig. 2) to simplify transfer of the harvest unit boundary to the timber harvest plan.

The ROUTES program—The ROUTES program allows the planner to rapidly identify road gradelines and to develop a road pattern within the harvest area. The program uses the DTM of the area as a source for terrain data. The planner can use the digitizer cursor to estimate the grade and distance between selected control points. The cursor can then project a gradeline between control points at the estimated grade. Operation of the program is similar in principle to manual map use and to field-based techniques that planners traditionally have used to plan forest road systems.

After a gradeline has been projected on the map, the profile view (fig. 4) and the planimetric view (fig. 5) of the route can be produced by the program as can a printed summary of the stations, elevations, grades, cuts and fills, and side slopes along the route.

The program can also be used to produce rough profile plots and summaries of side slopes along existing roads within the harvest planning area.

The SLOPE program—The SLOPE program produces overlays at map scale that delineate topographic attributes (that is, slope, aspect, or elevation or combinations) within ranges set by the planner. The program also provides a printed summary of acreage of the plotted attributes. Overlays can be produced at various resolutions based on the grid size of the digital terrain model. An example of a slope overlay, produced with a resolution of 16 digital terrain model grid cells per slope attribute cell, is shown in figure 6. These overlays are useful for several reasons. If the planner wants to prescribe yarding systems based on terrain steepness, a slope-attribute plot will delineate the appropriate boundaries. If the planner decides that the areas where winter logging is feasible are constrained to terrain on south, southwest, and west aspects below 3,500 feet elevation, and wants the acreage and location of that terrain, the SLOPE program can provide this information. Other topography-related information useful for land management (for example, to allocate planting stock, schedule slash burning, or locate wildlife winter range) can be obtained by using this program.



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HIGHLEAD TOWER HEIGHT:                 90 FEET
TAILBLOCK HEIGHT:                       2 FEET
MAXIMUM SLOPE RIGGING DISTANCE:      1200 FEET
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Figure 3—The highlead corridor profile plot as produced by the HIGHLEAD program.

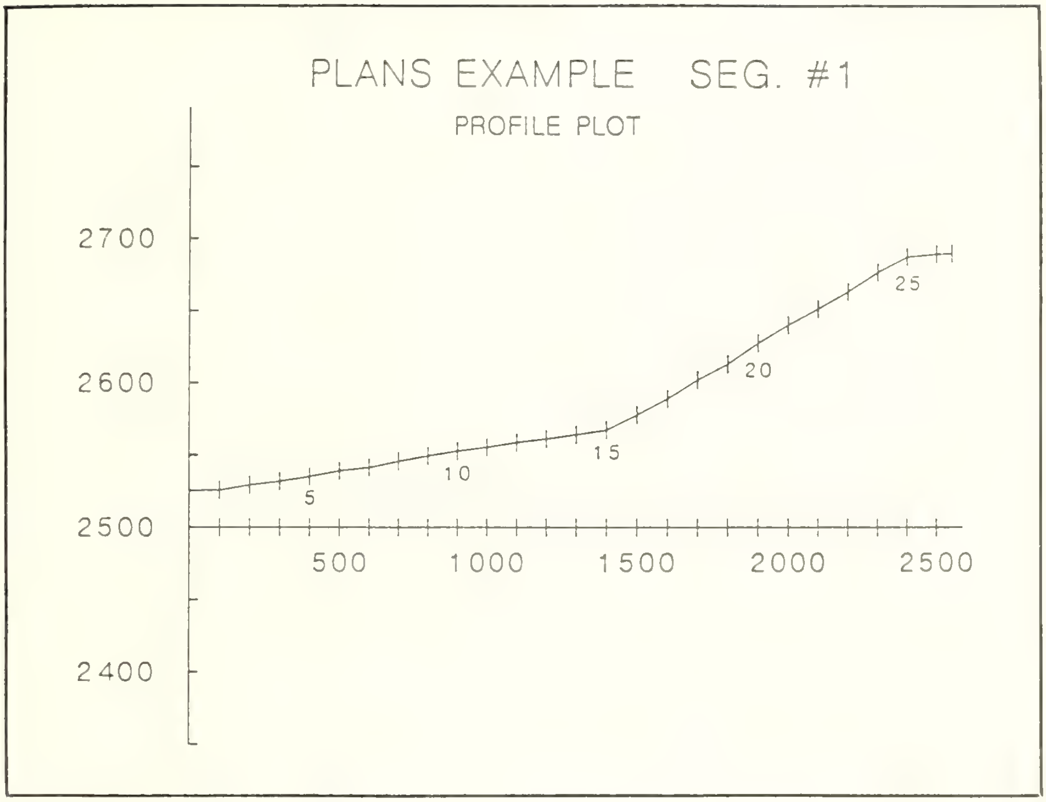

Figure 4—Profile plot of a road as produced by the ROUTES program.

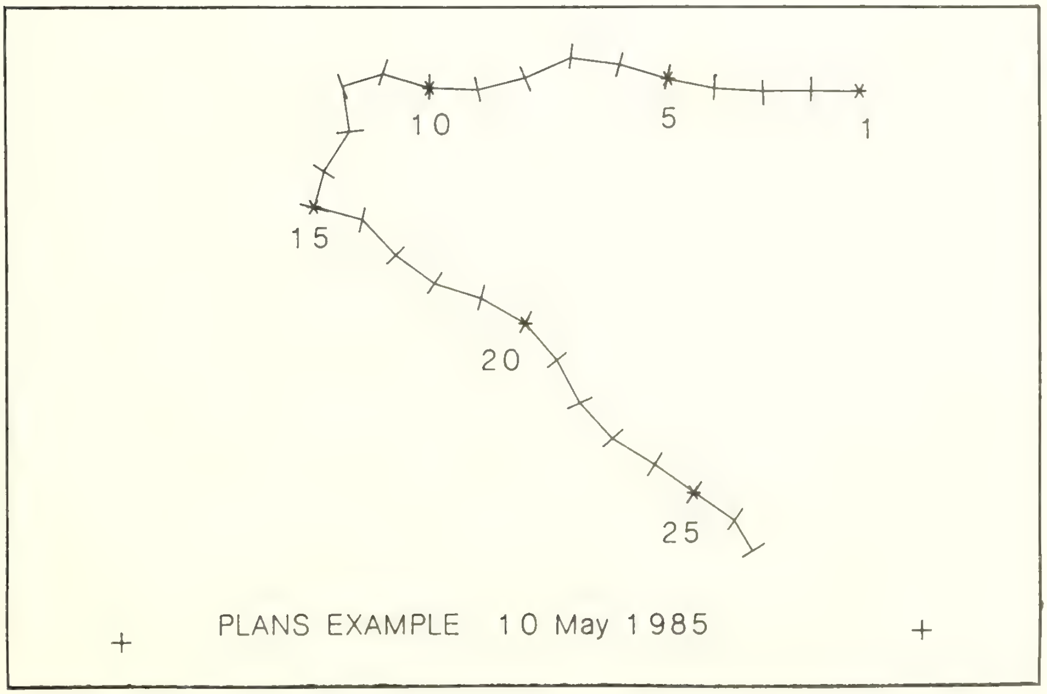

Figure 5—Planimetric plot of a road's location as produced by the ROUTES program.

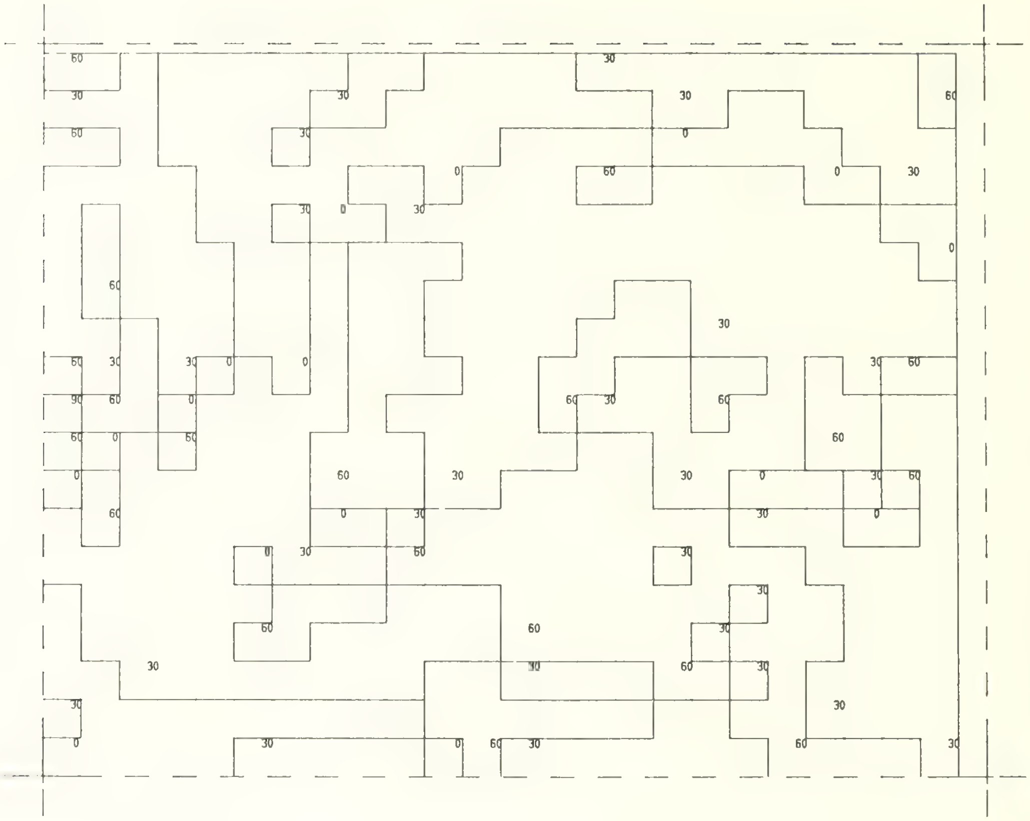

Figure 6—Slope overlay as produced by the SLOPE program.

The VISUAL program—The VISUAL program produces perspective views of terrain, roads, and harvest boundaries from user-selected viewpoints. These perspective views provide a preview of the visual impact of proposed harvest activities. Perspective views, such as the one shown in figure 7, show only the areas of terrain and harvest activity visible from the selected viewpoint. VISUAL also provides the planner with the opportunity to view a three-dimensional projection of the topographic map (represented by the digital terrain model). Such projections help the planner to get a better sense of the general lay of the land in early stages of planning.

The SIMYAR program—The SIMYAR program is a cable logging simulation model that uses a harvest unit's geometry, timber stand characteristics, and yarding equipment specifications to estimate cost and productivity of yarding. The planner can use the estimates to compare alternative timber harvest plans. Both parallel settings yarded with mobile yarders and fan-shaped settings yarded to a central landing can be modeled by the SIMYAR program. Output from SIMYAR includes a summary of costs and productivity for various yarding systems (see fig. 8) and information that details yarding production and volume statistics for the unit.

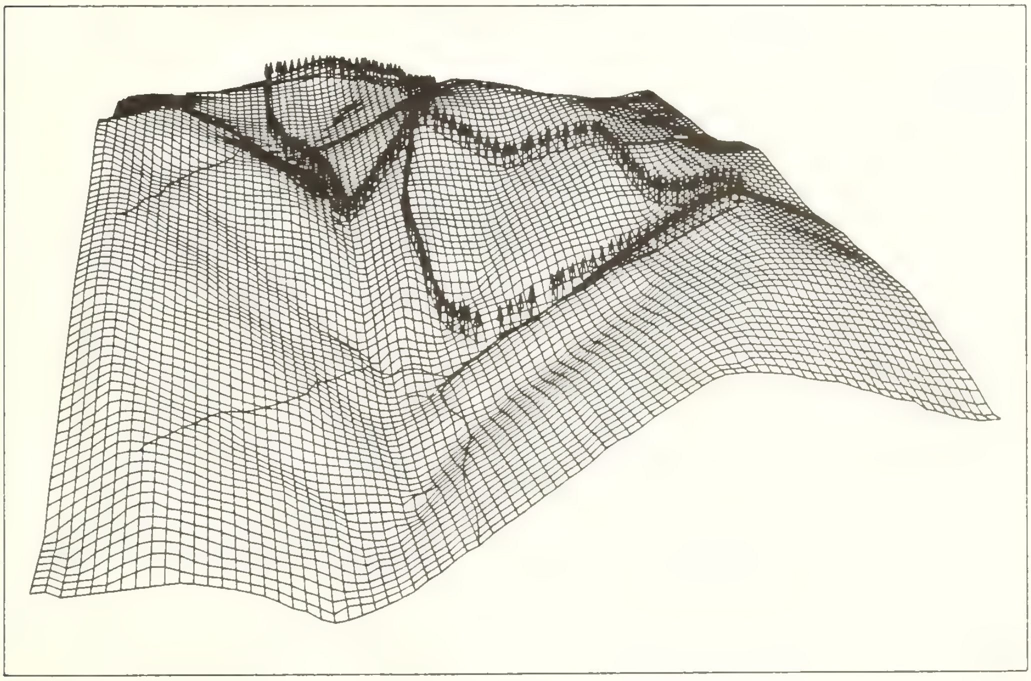

Figure 7—The perspective plot as produced by the VISUAL program.

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                 SPEARFISH SALE:  UNIT #3      5 Jun 1985

Type of system:  SKAGIT BU-90:  LIVE SKYLINE
Operating cost per hour is 203.86 dollars.
The set up cost for the logging system is 1000.00 dollars.
The maximum slope yarding distance is 798.88 feet.
The maximum lateral yarding distance is 24.15 feet.
The average system payload is 15000.00 pounds.
The preferred log length is 40.00 feet.
The minimum log length is 12.00 feet.
The small end merchantable diameter limit is 6.00 inches.
33.00 skyroads are required on the harvest unit.
The average road services .42 acres.
Road change time: 1.15 hours.
The stand contains 34230 board feet per acre (Scribner).


                         TURN STATISTICS

                      Mean     Std dev   Minimum   Maximum

Weight (Pounds)     6383.40    3164.67    232.01  14225.03
Volume (Cu. Ft.)     127.67      63.29      4.64    284.50
Volume (Bd. Ft.)     631.95     368.74         8      1548
Number of logs         3.24       1.00      1.00      4.00
Cycle time (Min.)      6.32        .45      5.25      7.23

Cycle times determined using user selected regression equations.


                  DISTRIBUTION OF TURN WEIGHTS

 Weight per                                                Relative
turn (Pounds)                                              frequency
-------------------------------------------------------------------------
1 - 1500        **                                           .0476
1501 - 3000     **                                           .0476
3001 - 4500     ************                                 .2381
4501 - 6000     *****                                        .0952
6001 - 7500     ************                                 .2381
7501 - 9000     *******                                      .1429
9001 - 10500    *****                                        .0952
10501 - 12000   **                                           .0476
12001 - 13500                                                .0000
13501 - 15000   **                                           .0476
-------------------------------------------------------------------------
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Figure 8—The analysis summary produced by the SIMYAR program.

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                    SPEARFISH SALE:  UNIT #3       5 Jun 1985

                         DISTRIBUTION OF LOGS PER TURN

Number of logs                                                      Relative
  per turn                                                          frequency
-----------------------------------------------------------------------------
     1          **                                                    .0476
     2          ************                                          .2381
     3          *******                                               .1429
     4          *****************************                         .5714
-----------------------------------------------------------------------------



                          DISTRIBUTION OF CYCLE TIMES

 Time per                                                           Relative
turn (min.)                                                         frequency
-----------------------------------------------------------------------------
0.00 -  .72                                                           .0000
 .73 - 1.45                                                           .0000
1.46 - 2.17                                                           .0000
2.18 - 2.89                                                           .0000
2.90 - 3.62                                                           .0000
3.63 - 4.34                                                           .0000
4.35 - 5.06                                                           .0000
5.07 - 5.78     *******                                               .1429
5.79 - 6.51     **************************                            .5238
6.52 - 7.23     **************                                        .2857
-----------------------------------------------------------------------------


                                  UNIT SUMMARY

         Unit area:                          13.86 acres
         Number of pieces yarded:            2244.00
         Number of turns:                    693.00
         Total yarding time:                 72 hours  57 minutes
         Total yarded volume:                884.74 cunits
                                             437.94 M board feet

                                  YARDING COST

         Total yarding cost:                 $ 23374.85
         Yarding cost:                       $ 26.42 /cunit
                                             $ 53.37 /MBF
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Figure 8—The analysis summary produced by the SIMYAR program (continued).

Developing a Harvest Plan With PLANS

The topographic map is the foundation of a timber harvest plan developed using PLANS. The first question from a prospective PLANS user might well be, "Is the topographic map of my harvest area adequate (in scale, detail, and accuracy) to be used for planning?" The answer is yes, if the resulting map-based harvest plan fits closely enough to what can actually be achieved on the ground to provide:

1. Information that a land manager can confidently use to evaluate the economic and environmental consequences of a specific timber harvest.
2. A harvest plan that can be sustained as a pattern for layout. The size and impact of the necessary layout adjustments (that is, fitting the harvest plan to the terrain) can be accommodated without a major overhaul of the harvest plan.

Users of PLANS need topographic maps sufficient in accuracy and scale for map-based planning. Maps with a scale of 1 inch to 400 feet and 20-foot contours are recommended, although scales up to 1 inch to 1,000 feet with contours up to 50 feet can be used.

Practical Sequences of Use for PLANS Programs

The MAP program must always be used first with PLANS. After the general area to be planned has been marked on the topographic map, the planner uses the MAP program to build the DTMs of the planning area by tracing the contour lines.[6]

After the DTM of the planning area has been constructed, any of the design programs can be used. The basic functions performed by the PLANS programs are built around analytical routines commonly used for planning cable logging operations. Special situations may require that these basic functions be performed in a different sequence or that more emphasis be placed on one function. For instance, in one area the required road pattern may dictate the type and placement of the yarding system. In such a case, the planner may want to develop the road system first using the ROUTES program and then develop yarding coverage using the SKYMOBILE, SKYTOWER, and HIGHLEAD programs. In another area, the required yarding system may dictate where the roads are to be constructed. In this case, the yarding analysis programs may be used prior to the route-location program. Whatever the case, the PLANS programs allow the planner to quickly verify that a harvest plan is workable. With the exception of the MAP program, the PLANS programs can be used in any order. Each program operates independently and requires only that a digital terrain model has been produced and loaded prior to running the program. The PLANS package does not force the planner to use all the programs contained in the package. The planner may choose to use only those PLANS programs that are suited to the particular planning task.

The PLANS package does not force the user into a structured planning process. This may appeal to those planners who do not want their creativity and intuition constrained by required procedures. Other planners, who want a more detailed explanation of how to use the PLANS package, should review the following planning procedure. (Suggestions for managing and organizing documents while developing a harvest plan are given in the appendix.)

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[6] Even when existing DTM tapes are converted to the correct structure for use in PLANS, they are loaded by using the MAP program.

An Example Approach to Harvest Planning With PLANS

We were asked to make a timber harvest plan for a 3,200-acre unit in the Cascade Range at the Wind River Experimental Forest, Gifford Pinchot National Forest, Washington. This provided an opportunity to put PLANS to a practical test and to develop a methodology for its use. Efficient and thorough planning requires a logical and structured methodology. Although PLANS does not force users into a structured planning process, it does not prevent them from using one. The approach taken in developing the Wind River plan is shown in figure 9. Even though this schematic can fit a range of planning situations, the variability of harvesting situations makes it unlikely that this generalized harvest planning approach will fit all situations.

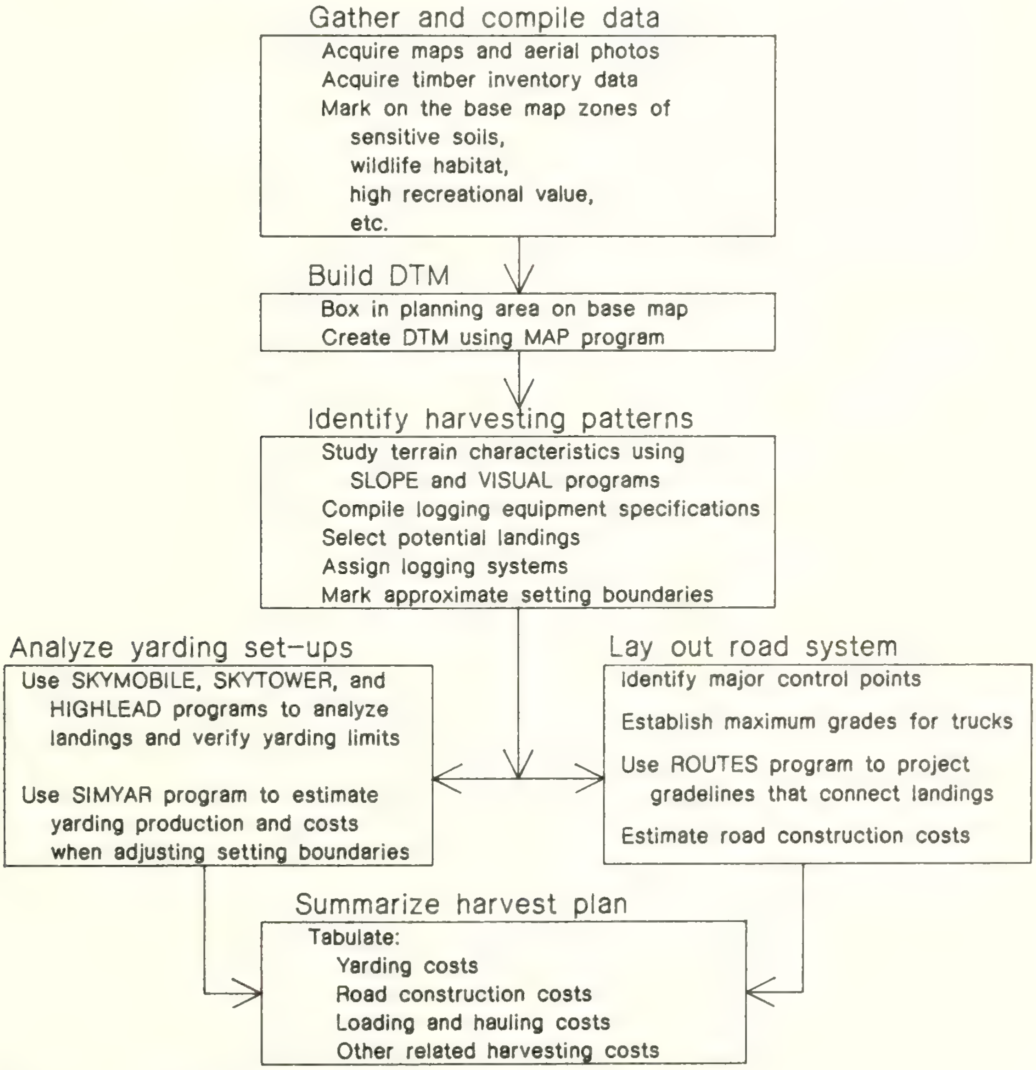
Gather and compile data
Acquire maps and aerial photos
Acquire timber inventory data
Mark on the base map zones of
sensitive soils,
wildlife habitat,
high recreational value,
etc.
Build DTM
Box in planning area on base map
Create DTM using MAP program
Identify harvesting patterns
Study terrain characteristics using
SLOPE and VISUAL programs
Compile logging equipment specifications
Select potential landings
Assign logging systems
Mark approximate setting boundaries
Analyze yarding set-ups
Use SKYMOBILE, SKYTOWER, and
HIGHLEAD programs to analyze
landings and verify yarding limits
Use SIMYAR program to estimate
yarding production and costs
when adjusting setting boundaries
Lay out road system
Identify major control points
Establish maximum grades for trucks
Use ROUTES program to project
gradelines that connect landings
Estimate road construction costs
Summarize harvest plan
Tabulate:
Yarding costs
Road construction costs
Loading and hauling costs
Other related harvesting costs

Figure 9—A preliminary harvest planning approach that incorporates the PLANS package.

As indicated in figure 9, many tasks must be completed before design of the harvest unit can begin. The tasks include collecting and studying information that describes the planning area, compiling a list of yarding equipment needed to accomplish the harvesting objectives, and developing a first-try or best-hunch projection of an overall harvesting pattern. These tasks have always been important prerequisites to using computer programs for harvest planning (Burke 1984), and they continue to be with PLANS.

A large-scale topographic map and aerial photos of the area must be obtained before planning can begin. Additional information to be collected may include maps of soil type, geologic hazards, timber type, land ownership, silvicultural stand treatment priority, stream classification, and recreation area; visual resource management objectives; and the primary transportation plan. The boundary of the planning area must be delineated on the topographic base map; areas requiring special consideration, such as unstable slopes, specialized wildlife habitat, and special streamside buffer zones, also have to be shown.

The planner should compile a generic list of ground-based and cable yarding systems that may be needed to accomplish the harvest objectives. This list should include yarder types, general rigging configurations, line sizes, line lengths (that is, maximum yarding reach), potential yarding payloads, skidder types, and maximum uphill and downhill hauling grades for ground-based equipment. Yarding equipment will be selected from this list later in the planning process.

Before identifying an overall harvesting pattern for the planning area, the planner should study the general form of the terrain. It is often helpful to separate the more gently sloped areas where the timber can be yarded with ground-based equipment from the steeper areas that require the use of cable yarding systems. The SLOPE program can be used to create map overlays that break the planning area down into whatever ground-slope categories the planner specifies. For instance, the planner may want to identify all areas that have a ground slope of 0 to 20 percent, where a feller-forwarder can operate. Other overlays can be produced that identify areas with a ground slope of 20 to 40 percent, where a crawler-tractor can operate. The remaining areas may require cable yarding systems.

The planner must recognize on the topographic map terrain patterns that look promising for long- and short-span skyline, highlead, or ground-based yarding systems. These patterns should be shown by a different color for each yarding system on a topographic map overlay of the planning area (see appendix). The approximate locations of landings, key yarding corridors, skid trails, roads, and setting boundaries for each harvesting system should be included on this overlay. Extreme accuracy is not needed when sketching in these locations, which will be refined in the yarding analysis stage. Numerous attempts may be needed to develop this overall harvesting pattern, depending on the judgment of the planner and the complexity of the terrain.

This harvesting pattern overlay serves as a general guide for subsequent analysis of individual yarding setups (fig. 9). The yarding analysis programs, SKYMOBILE, SKYTOWER, and HIGHLEAD, can be used to evaluate and refine the general setting boundaries that were sketched on the overlay. The SKYTOWER and HIGHLEAD programs allow the planner to quickly identify the area that can be yarded to a central landing. If a landing shows promise, the planner can examine individual profiles and adjust the setting boundary. The SKYMOBILE program, which analyzes payload and span combinations on individual profiles, provides an effective tool for planning use of mobile yarders operated from parallel settings. Landing locations, rigging configurations, turn volumes, and yarding limits can be modified until satisfactory yarding coverage is obtained.

As the analysis of landings proceeds, a mosaic of setting boundaries is developed and plotted on another overlay. Inevitably some gaps in the harvesting pattern will be identified and alternative landings will need to be selected. After enough landings have been added to ensure that all timber within the harvest area can be harvested, the planner can use the SIMYAR program to make estimates of the yarding production rates and costs. When a parcel of timber can be yarded to two or more landings, the production and cost estimates can be used to select one option over another.

The planner can use the ROUTES program to develop a road network that connects all the landings necessary to harvest the area. During this process, the planner may find it impossible to access some of the landings. If so, alternative landings may need to be selected and analyzed with the SKYTOWER, SKYMOBILE, or HIGHLEAD program before the road system can be completed. Designing the roads before the harvest units may sometimes be more efficient for the planner.

After the setting boundaries and road locations have been identified, the planner can use the VISUAL program to examine the visual impact of the harvest plan from selected viewpoints. If the visual impact of some feature of the plan is too great, the PLANS programs can be used to modify the feature.

After developing an initial harvest plan for the planning area, the planner may wish to develop and compare alternative plans that focus on competing resource management objectives. Alterations to the initial plan may range from minor revisions, such as changes in the size-class of equipment to be used or the location of selected landings and roads, to a complete revamping. When the PLANS package is used to develop alternatives, much of the data needed to compare alternatives on an economic basis are already generated by the various design programs. The summaries of grade, sideslope, and road length produced by the ROUTES program are useful in estimating costs of road construction. The yarding production and cost estimates, along with the areas and harvest volumes of settings, are available from the SIMYAR program output. The planner can use these data in any economic comparison that is appropriate.

Cost and Benefits of Preliminary Harvest Planning

A timber harvesting operation is a materials handling activity that can be made more efficient through the application of rigorous planning methods (Dykstra 1976). Sauder and Nagy (1977) projected, for one specific coastal British Columbia harvest area, logging and hauling costs that ranged from $3,582 to $3,120 per acre, depending on the choice of harvesting system. This $462-per-acre range in costs, which is 14 percent of the average total harvesting and hauling cost, represents the potential savings that can result when an area is intensively planned. Included in this $462 are estimated differences in costs for roads, hauling, loading, felling, and yarding that result when different yarding systems are selected to harvest the same area. All these cost components are related through complex interactions between the logging and transportation systems. Rigorous analysis of each component of the harvesting and transportation systems is required if the highest possible return from timber harvest operations is to be achieved.

Savings in the harvesting and hauling cost for an area can result from two processes carried out during the preliminary planning. First, identify the harvesting and transportation system that is best suited to local topography and timber conditions. Second, lay out the harvest area to provide optimum operating conditions for the selected harvesting system. Even in areas where only a limited range of logging equipment is available, considerable savings can be achieved by laying out the area so that available equipment can operate efficiently.

The PLANS package enables the planner to evaluate possible harvesting and roading alternatives so that the appropriate harvesting system for a particular location can be identified. The cost for developing a preliminary harvest and transportation plan using the PLANS package is estimated to be about $1 per acre.[7] With harvesting and hauling costs of several thousand dollars per acre, a planning cost of $1 per acre represents only a fraction of a percent of the total cost incurred to deliver timber to the market. With the potential for saving 10 percent or more of harvesting and transport costs through proper selection and application of harvesting systems, this cost for planning should be easily justifiable.

The benefactors of improved harvest plans often are not part of the management unit that must pay for the planning; hence, the economic profits accrued from planning cannot be internally recycled to sustain planning. Additional planning costs, necessary to maximize (or at least increase) net revenues from harvesting operations must be justified, but the planning unit is not credited for the increase in net revenues. In such situations, additional expenditures for harvest planning must be justified through net profit to the overall organization, rather than as just an extra cost. Convincing upper management to take such a view can often be a daunting task; however, the planner now has, in PLANS, a tool that greatly reduces the magnitude of preliminary planning costs and that should make justification somewhat easier.

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[7] Twito and McGaughey (1984) experienced planning costs using PLANS of $0.43 per acre; however, this estimate did not include costs of owning and operating the computing facility.

In addition to the financial benefits associated with intensive preliminary harvest planning, environmental benefits also usually occur. By selecting the right type of logging system for local terrain and timber conditions, soil disturbance (Megahan 1980, Rice and others 1972) and residual stand damage (Aho and others 1983, Fieber and others 1982) can be minimized. Construction of roads and landings, which has been shown to be the major contributor to erosion and water quality problems, can be minimized (Amaranthus and others 1985). The impact of a range of proposed environment restrictions on harvesting operations can be evaluated (Reutebuch and Murphy 1986), and the restrictions that best meet all management objectives can be applied to the harvest operation.

The use of an intensive preliminary harvest planning procedure ensures that land managers have based harvesting decisions on a thorough analysis of all available data and are seen to be doing so by concerned public groups. The use of computer-aided harvest planning techniques assists the planner in this analysis and provides ample documentation of the thoroughness and completeness of the planning effort.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 30.5 centimeters
1 cubic foot = 0.03 cubic meter
6,000 board feet = 28.3 cubic meters
1 acre = 0.40 hectare
1 cubic foot per acre = 0.069 cubic meter per hectare
1 pound = 453.6 grams

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Appendix

Suggestions for Managing Documents When Developing a Harvest Plan

Putting together a harvest plan involves the use of a large number of documents regardless of whether a totally manual or a computer-assisted procedure is used. The documents include large maps, aerial photographs, inventory data, and often a large number of worksheets and computer output sheets. Organization of these documents into a manageable and coherent form is essential to maintain the credibility of the harvest plan and to communicate the plan to others. The document management techniques that follow help to minimize the amount of drafting and nonproductive paper shuffling that seems to occur.

Use of transparent overlays—Timber harvest plans are usually drafted on a base, usually a large-scale topographic map. Often several smaller map sheets must be combined to make a base map that covers the entire area being planned. Map sheets must be carefully aligned and securely joined, mismatched contour lines along the joins must be adjusted, and the boundary of the planning area must be carefully marked. The contour lines on the base map can then be traced to produce a DTM of the planning area for use with the PLANS package.

The original base map used for building the DTM should be used to develop the harvest plan. This ensures that the elevation data in the DTM correspond properly with the contour lines on the base map used for planning. Because of slight differences in the alignment of adjacent map sheets and differential shrinkage of individual map sheets, a replacement base map, pieced together at a later date, probably will not exactly match the original base map and therefore should not be used when developing the harvest plan.

The orginal base map can be used throughout the entire planning process if it is protected with transparent overlays. The use of overlays saves time and expense by eliminating the need to assemble multiple copies of the base map and by preventing the introduction of differences between the DTM and the actual copy of the base map used for planning. In addition, use of overlays encourages the planner to sketch more alternatives and makes modifying or redrawing of portions of the harvest plan much quicker and easier.

Wide rolls of clear acetate film suitable for preliminary planning can be purchased from drafting supply firms. This material, although not as dimensionally stable as Mylar, can be purchased for a fraction of the cost of Mylar. Sheets of acetate film can be cut to any size needed for developing the harvest plan. With an overlay sheet taped to the base map, the planner can freely sketch details and write comments anywhere in the planning area without defacing the base map. Errors can be quickly corrected. If an overlay sheet becomes cluttered, it can be replaced with a new one. Several sheets, each containing a portion of the overall harvest plan, can be registered on the base map and viewed simultaneously. One overlay sheet may contain the road network, another may contain the landing locations, and another may show unit boundaries.

Water-permanent, felt-tipped pens, sometimes referred to as "overhead projector" pens, are recommended for drafting the harvest plan onto the acetate film. These pens are available in a variety of line weights and colors and can be purchased from office supply firms. The pens with the finest tips should be selected for harvest planning work. Water-permanent ink dries quickly (usually in a matter of seconds) when applied to the acetate film. This eliminates the smudging problem that occurs when water-soluble pens are used on acetate film. In addition, acetate overlays drafted with these pens can be taken to the field in wet weather without fear of smearing.

Erasures and corrections of features drawn with water-permanent ink on acetate film can be made in two ways. First, lines can be selectively erased by vigorously rubbing with a soft eraser. (Slightly moistening the eraser speeds up the process and reduces the amount of rubbing needed to remove a line.) Second, large areas or entire overlays can be wiped clean with a tissue or cloth dampened with ethyl (rubbing) alcohol.

The alignment of each overlay sheet with the base map should be recorded so that if the overlay is removed, it can be properly realigned with the map at a later time. This is most easily accomplished by marking two or three reference points on the overlay. The corners of the DTM boundary can be used as convenient reference points.

It is advisable to cover the base topographic map with a clear overlay sheet immediately after the boundaries of the DTM units have been drawn on the base map and before starting to build the DTM with the MAP program. This ensures that the planner does not inadvertently draw on or mar the base map while tracing the contour lines with the digitizer cursor. The overlay sheet also provides a smooth surface to slide the cursor on while tracing contour lines. As each successive contour line is traced, the planner can keep track of progress by drawing a tick mark through the contour line on the overlay sheet. It is sometimes helpful to trace the streams on the overlay sheet with a blue pen to better define the general form of the terrain before starting to digitize the contour lines. The overlay sheet used while tracing the contour lines is simply a work sheet and can be cleaned or discarded after the DTM has been built.

The planner may wish to use several overlay sheets when sketching an initial estimate of the overall harvest and road patterns needed for the area. A different overlay sheet and pen color for each harvesting system can be used to sketch the approximate locations of landings and setting boundaries. The approximate locations of roads can also be sketched in a different color on a separate overlay sheet.

Overlay sheets of the overall harvesting pattern can be left in place on the base map and can be used as general guides when the PLANS analysis programs are used to verify and adjust setting boundaries and road locations. Additional overlay sheets, on which the final harvest unit boundaries and road locations are drawn, can be taped over them. The PLANS yarding analysis programs produce plots of setting boundaries that can be slipped between the base map and the overlay sheet and then traced onto the overlay sheet. The route location program produces plots of road locations that can be transferred to an overlay in the same fashion.

After all analyses have been completed and the locations of landings, setting boundaries, and road locations have been finalized and drawn on various overlay sheets, the entire harvest plan can be traced from the acetate film to a more dimensionally stable Mylar base for storage or for subsequent reproduction.

Organization of the PLANS computer output—In addition to drafted harvest plan overlays, a considerable volume of computer output (printed tables and paper plots) is generated by the PLANS analysis programs. This output must be keyed to the harvest plan overlays and organized in a form that enables the planner to quickly review the assumptions that were used in the analysis of each detail of the plan. Some of these assumptions are subsequently modified, and details of the plan must be reanalyzed as the preliminary harvest plan is reviewed and adapted into an operational field layout.

A simple, straightforward method of organizing the computer output associated with a harvest plan is by landing and road number. As the output is produced, it should be assembled in a ring binder. If landings are assigned numbers that are prefixed by the number of their access road, the ring binder can be subdivided into major sections by road number. Each section can be further divided into the following catagories: yarding analysis output, yarding production and cost estimates, and road location and design.

The ring binder should include separate sections for output associated with visual and terrain attribute analyses that are carried out using the VISUAL and SLOPE programs of PLANS.

This loose-leaf format, coupled with the use of transparent overlays of the harvest plan, enables the planner to quickly modify and update the plan as it progresses toward implementation.

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PNW-GTR-200

The MAP Program: Building the Digital Terrain Model

Roger H. Twito, Ronald W. Mifflin, and Robert J. McGaughey

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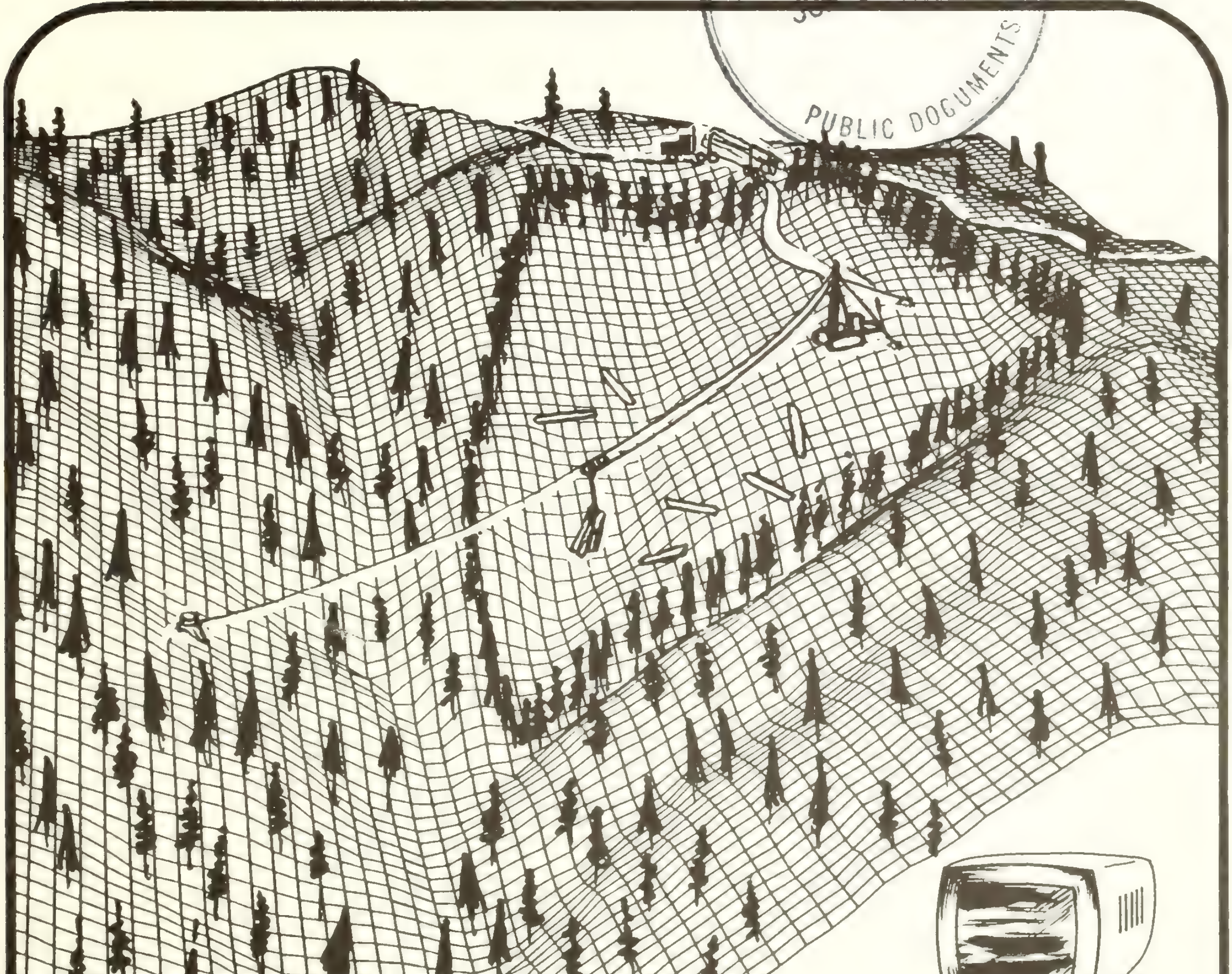

PLANS

Preliminary **L**ogging
Analysis **S**ystem

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Abstract

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PLANS, a software package for integrated timber-harvest planning, uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. MAP, an integral program in the PLANS package, is used to construct the digital terrain models required by PLANS. MAP establishes digital terrain models using digitizer-traced contour lines from topographic maps, which are, in turn, processed into an elevation grid and stored in matrix form. MAP builds continuous digital terrain models that can cover large planning areas and builds them to any elevation grid spacing desired. Though the MAP method does not always result in digital terrain models that are a perfect equivalent to the topographic map, they should be adequate for planning. A guide giving detailed operating instructions for the programs is included.

Keywords: Timber harvest planning, computer programs/programing, models, logging operations analysis/design.

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Introduction

Digital terrain models are data files, accessible to computers, that provide detailed topographic information. This report presents a process for producing gridded digital terrain models from topographic maps. The models are used by a system of computer programs called PLANS (acronym for preliminary logging analysis system) (Twito and others 1987) to develop large-area timber-harvesting and road-network plans. The digital terrain models add greatly to this efficiency by providing convenient and automatic access to the large amount of data on slopes and elevation profiles that must be analyzed in timber-harvest planning.

The digital terrain models are produced by hand-tracing contour lines from a topographic map (with a digitizing cursor). Digitized contour data are converted by the program to a gridded elevation matrix, which is stored for later use. Large planning areas can be subdivided into smaller units for purposes of inputting data. These units, after the digital terrain model is constructed, can be recombined to provide continuous coverage across maps that are larger than the digitizer tablet.

Digital terrain models (DTMs), digital elevation models (DEMs), and digital terrain tapes (DTTs) are part of a system that uses numeric data to represent the surface elevation of the ground. These data, referred to as a digital terrain model (DTM) for the remainder of this report, consist of numerical arrays. The concept of a DTM may be more readily visualized as a model that is equivalent to a topographic map. Both the DTM and the topographic map are models that represent the surface elevation of the earth. A topographic map translates the surface to a form readily understood and visualized by people, and a DTM translates the surface into numeric data readily processed by a computer.

Documented use of DTMs began in the early 1950's at the Massachusetts Institute of Technology (Miller 1957). The system was originally developed to represent the elevation surface of a highway construction zone; the goals were to reduce the burden of routine calculations on transportation planners and to investigate alternative alignment strategies (Grist 1972). In the late 1950's, the Defense Mapping Agency Topographic Center (DMATC) began producing digital terrain data as a byproduct of the construction of plastic relief models of the earth's surface (Carter 1984). DMATC, encouraged by military and civilian groups, developed increasingly complex data-collection systems that, in turn, provided for the development of gridded DTMs. DMATC began releasing this collected data as DTTs in the early 1960's. DTTs, characterized by a 200-foot ground spacing between gridlines, were criticized for their lack of quality (Carter 1984). The original DTTs have been improved by the U.S. Geological Survey (USGS) and are now available as DEMs keyed to the 1:250,000 topographic map series. In addition to the 1:250,000 DEMs, USGS produces 7½-minute DEMs as a byproduct of orthophoto mapping. These DEMs, with a 30-meter spacing between elevation points, are keyed to the 7½-minute topographic maps. Currently about 15 percent of the United States is covered by DTMs (Carter 1984). The development of a DTM used specifically for forest-resource planning was reported by Lemkow (1977). Even though this model was limited by computer-system constraints, it demonstrated the usefulness of a DTM for timber-harvest planning.

Building DTMs With the MAP Program

The MAP program creates the DTMs used by the rest of the PLANS programs. DTMs are created in three basic operations:

1. Establishing the boundary of the DTM.
2. Digitizing the DTM's contour lines.
3. Converting the digitized contour-line data into a DTM.

Establishing the Boundary of the DTM Unit

The topographic map of the project planning area is the source from which DTMs are built. The physical size of the topographic map(s) and the resulting DTM coverage area require careful preparation before building the DTM, especially when large areas are being planned for. Usually, large areas have to be subdivided into smaller DTM units. Subdivision is required when:

1. The DTM coverage area is larger than the digitizer tablet, or
2. The DTM coverage area cannot, as a single unit, meet the desired gridline spacing.

When subdivision is required, the DTM coverage area is divided into equal-size, rectangular DTM units. Later, up to six adjacent DTM units can be loaded and combined into an enlarged DTM when the design programs in PLANS are used.

The first step in building a DTM is to delineate the planning area on the topographic map[1/] by carefully enclosing the planning area within a rectangle that defines the DTM coverage area. Next, the user enters the measured dimensions of the rectangle and the desired gridline spacing for the DTM (additional detail on gridline spacing is provided in the appendix), and the program determines if subdivision is required. If subdivision is needed, the program calculates the DTM-unit size necessary to obtain the desired gridline spacing and instructs the user on locating and marking the subdivision boundaries within the DTM coverage area.

Digitizing Contour Lines of the DTM Unit

After the DTM unit is enclosed in a rectangle, elevation data can be entered via the digitizer. First, the location of the DTM unit on the digitizer tablet is established by digitizing the lower left corner of the unit and a point on the lower boundary. Then a process-control menu is taped to the digitizer tablet. The DTM building process is controlled by the user, who simply digitizes inside the menu square labeled for the desired action. A typical sequence of events is as follows:

1. Enter the elevation of the lowest contour line on the DTM unit. (This is optional; the user may start with the highest or anywhere else.)

2. Enter the difference in elevation between adjacent contour lines; that is, the contour interval.

3. Enter the elevation increment mode, which is uphill or downhill. This causes the elevation of each new contour line to be set at the elevation of the last line digitized plus, if in the uphill mode, the contour interval.

[1/] The appendix provides more detail on the preparation steps for building a DTM from a topographic map.

4. Trace the contour line with the digitizer cursor. Digitized input automatically stops when the contour line being traced exits the DTM unit or, if the contour line is a continuous loop inside the DTM unit, when the traced loop has been completed.

This process is repeated until the DTM unit is completed or the user wants to change modes. As each line is digitized, it is plotted on the computer screen, which also shows the position of the digitizer cursor. This graphic aid shows the progress of the contour-line tracing operation. The user can stop this operation whenever convenient by digitizing the "terminate contour-line tracing" square in the menu; this action stores the completed contour lines as a partially completed and unprocessed DTM unit. The partially completed unit can be reloaded, and the contour-line tracing can be completed at another time.

The user can select several other menu options that permit variation of digitizing routine, correction of errors, and other operational conveniences. When all contour lines are digitized, the user can instruct the program to process the contour data into a gridded DTM.

Converting the Digitized Contour-Line Data to a DTM

The third and final operation in the process of creating the DTM units needed for operating the PLANS program is an automated process that converts the elevation and contour-line data into gridded elevation data and stores the DTM unit for later use. The user can also store the contour lines to preserve these data for plotting or reprocessing the gridded DTM. The process requires no user input but usually takes up to a minute of computer processing time.

Analytical Description of the MAP Program

A topographic map is the basic source of information used with the MAP program to build digital terrain models. We begin a simplified example of the process with the topographic map (fig. 1).

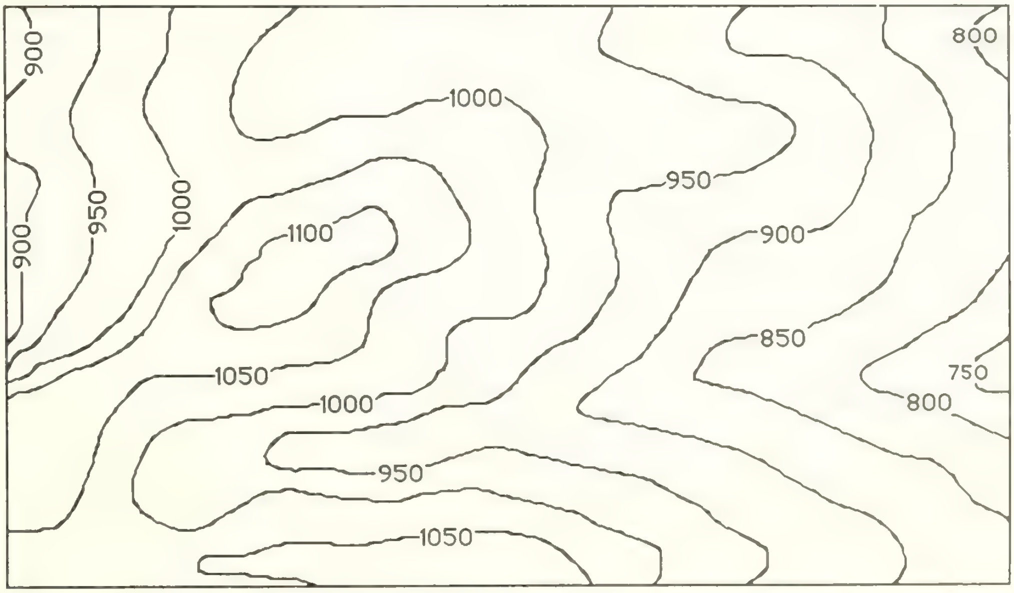


Figure 1—Topographic map from which a gridded DTM can be created.

Digitized Contour Lines as Source Data for DTMs

The user of the MAP program converts topographic maps, like the one shown in figure 1, to DTM data files by tracing each contour line with the digitizer cursor. Each contour line is stored with an elevation "header" (that is, the elevation of the contour line) and a series of closely spaced x and y coordinates, entered by digitizing, that describe the location of the contour line on the DTM unit. Collecting these data is the first step in building the gridded terrain model (fig. 2).

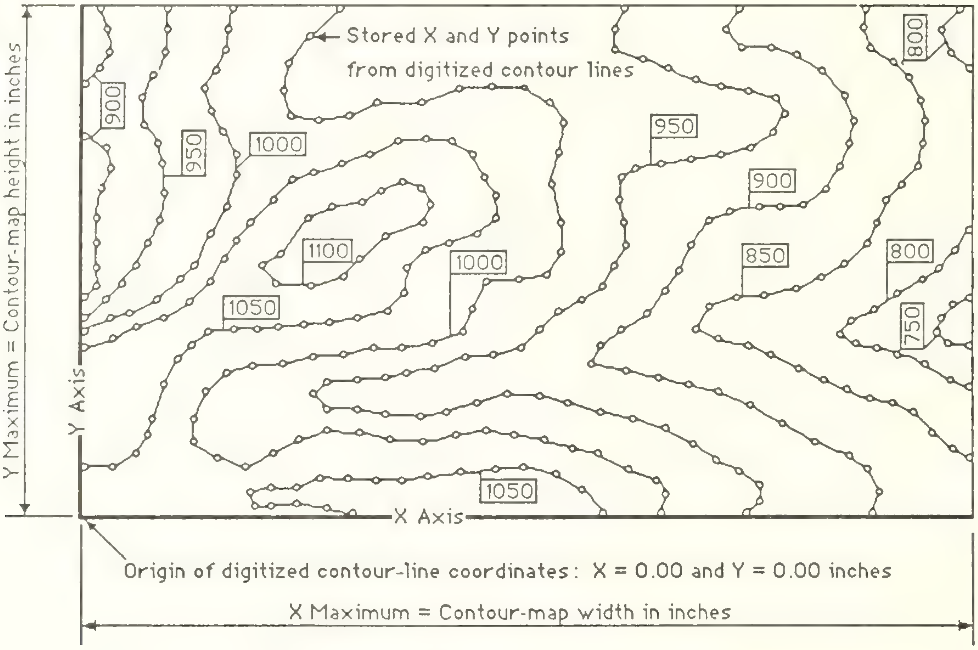

Stored X and Y points from digitized contour lines
900
950
1000
950
900
800
1100
1000
850
800
1050
750
1050
Y Maximum = Contour-map height in inches
Y Axis
X Axis
Origin of digitized contour-line coordinates: X = 0.00 and Y = 0.00 inches
X Maximum = Contour-map width in inches

Figure 2—Topographic-elevation model represented as a series of discrete x and y coordinate data sets collected by tracing the contour lines with a digitizer cursor.

These data alone constitute one type of DTM as the stored x and y coordinates with their associated contour-line elevations can be considered a numerical representation (model) of the topographic map. The data are, however, the source the gridded DTM is derived from. One reason for converting these data into a gridded DTM is the amount of disk storage space required; a gridded terrain model requires about 5 to 10 percent of the storage space needed for the terrain model in the contour-line form. Even though large amounts of storage space are required, the contour-line data should be stored on a magnetic-tape drive. Doing so allows the user to replot the hand-digitized contour lines and compare their accuracy with the original map. In addition, the stored contour-line data can be reprocessed by other DTM programs that address other analytical needs. Saving the contour-line data is a good general practice because the contour lines do not have to be retraced later.

The remaining steps in the process of creating a DTM, after hand-digitizing the contour lines, are automated and require minimal effort by the user.

The DTM Grid

Figure 3 shows a grid imposed on the contour map. An elevation in the DTM matrix will be derived at each intersection of gridlines.

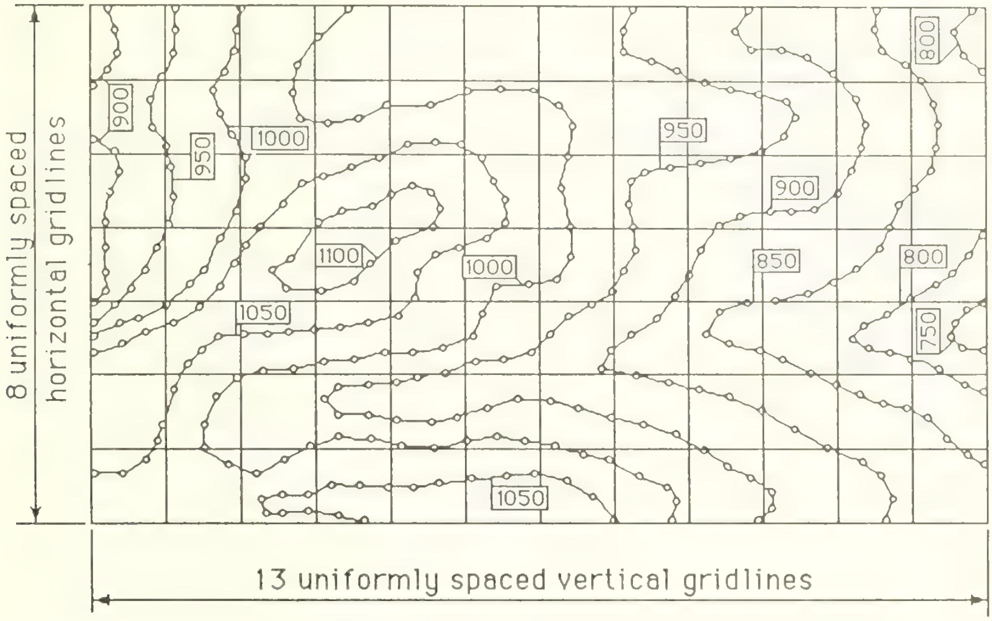
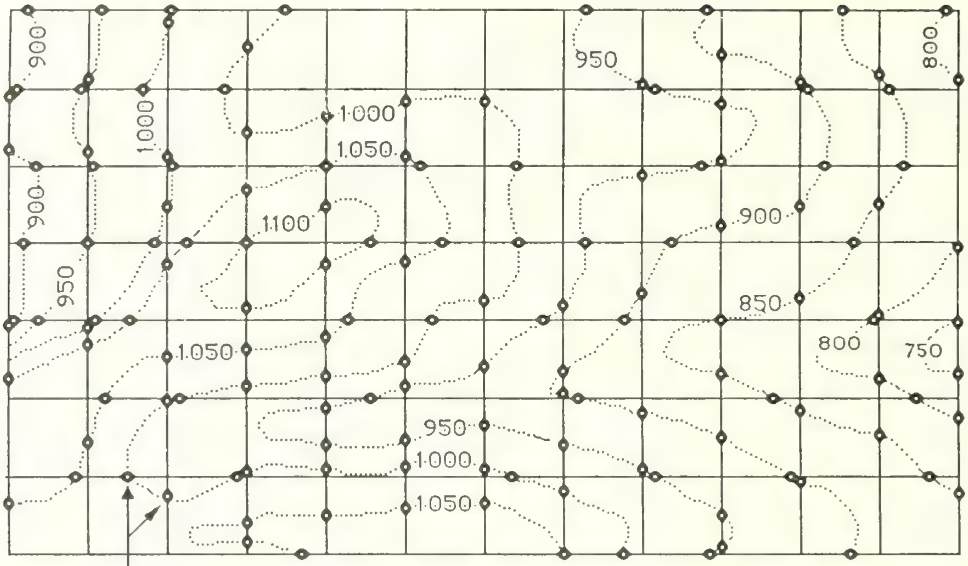

8 uniformly spaced horizontal gridlines
13 uniformly spaced vertical gridlines
900
950
1000
1100
1050
1000
950
900
850
800
800
750
1050

Figure 3—Digitized contour lines displayed with the square grid of the DTM.

The user chooses the spacing for the elevation grid of the DTM. Choosing a fine grid spacing will result in a DTM that corresponds accurately with the contour map; however, fine grids require excessive amounts of disk space. A grid spacing of 25 feet requires about 16 times as much disk space as a grid spacing of 100 feet. Using a fine grid also increases the number of DTM units needed to cover a given planning area and generally complicates planning activities. A grid spacing between 0.10 and 0.15 inch on the map is suggested as a suitable compromise between accuracy and convenience.

Intersections of Contour Lines and Gridlines

The next step in the process is shown in figure 4.



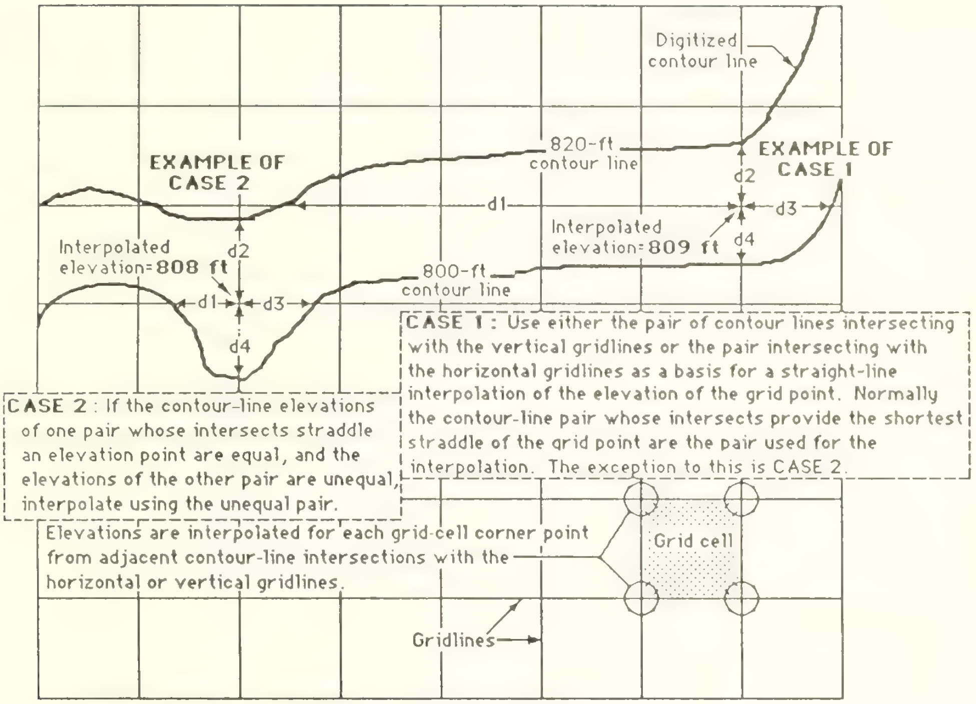
Contour line intersections with the gridlines are calculated and stored to be used for interpolating the elevations of each gridline intersection point.

Figure 4—Intersections of the square grid of the DTM with digitized contour lines.

Intersections of the contour lines and the horizontal or vertical gridlines are calculated and stored along with the elevation of the contour line. These data are used in an interpolation to determine the elevation of each corner point in the grid cell.

Interpolating Grid-Point Elevations From Contour-Line Intersections

The rules governing elevation interpolation in the grid cell are shown in figure 5. The interpolated elevation will have, at most, four adjacent contour-line intersections from which to calculate an elevation value. The interpolation will be based on two of these intersections: either the two on the horizontal gridline or the two on the vertical gridline. The value of saving the adjacent four intersections is that the interpolation algorithm can systematically choose the pair of intersections (horizontal or vertical) that will provide the most accurate elevation.



CASE 1 : Use either the pair of contour lines intersecting with the vertical gridlines or the pair intersecting with the horizontal gridlines as a basis for a straight-line interpolation of the elevation of the grid point. Normally the contour-line pair whose intersects provide the shortest straddle of the grid point are the pair used for the interpolation. The exception to this is CASE 2.

CASE 2 : If the contour-line elevations of one pair whose intersects straddle an elevation point are equal, and the elevations of the other pair are unequal, interpolate using the unequal pair.

Elevations are interpolated for each grid-cell corner point from adjacent contour-line intersections with the horizontal or vertical gridlines.

Figure 5—The two major interpolation rules that control the initial elevation-calculation process of the DTM.

The elevation interpolation for the grid point generally is established from either the two contour-line intersections (straddling the grid point) on the vertical gridline or the two contour-line intersections (straddling the grid point) on the horizontal gridline. The choice normally favors whichever pair (horizontal or vertical) surrounds the grid point by the narrowest straddle distance (case 1). If, however, the two straddling pairs of contour lines are of equal elevation (case 2), the algorithm bases the elevation interpolation on the contour-line straddle where the contour lines differ in elevation. Other grid-elevation points that are not surrounded by four contour-line-intersection points use combinations of whatever data are available. If surrounded by three contour-line-intersection points, the elevation will be interpolated between the two points that straddle the grid-elevation point. This usually occurs only on the edges of DTM units. If only two contour-line-intersection points are available, and the two do not straddle the grid-elevation point, no interpolation is possible, and the elevation from either contour line will be transferred to the grid elevation point. The same holds true if only one contour-line-intersection point is available; such circumstances occur only at the corners of DTM units.

Second-Stage Processing of DTM Elevations

After an initial elevation has been calculated for all the grid-cell corner points, a secondary DTM elevation-conditioning process occurs (fig. 6).

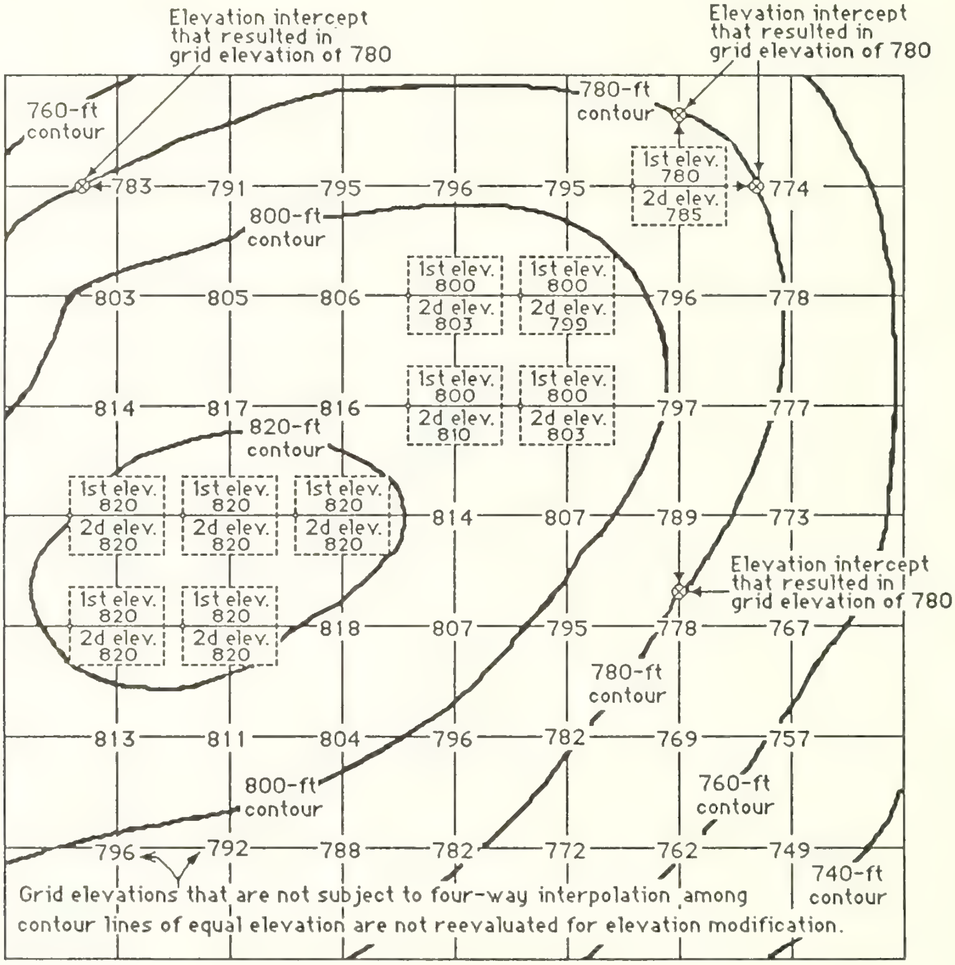
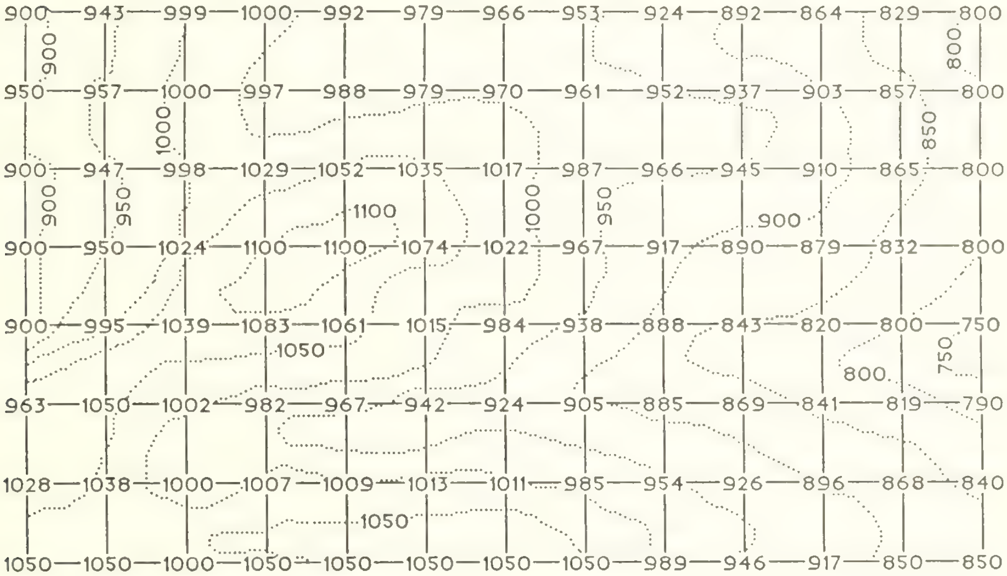


Figure 6—Areas for which grid elevations are initially interpolated between four equal-elevation contours are recalculated when a smoothed transition to adjacent, higher terrain can be provided.

All elevations for grid-cell corner points that were interpolated from four surrounding contour lines of equal elevation are flagged during the initial processing. In figure 6, this occurs 10 times (at locations marked with labels for first and second elevations). If adjacent grid points have higher elevations on one side of these flagged points and lower elevations on the opposite side, an additional straight-line interpolation is done along either the horizontal gridline or the vertical gridline. This smoothing algorithm prevents an abrupt elevation jump between adjacent elevations for grid-cell corner points. If there is no combination of higher and lower terrain bordering these grid-cell corner points, as is true for the 820-foot elevations shown in figure 6, the elevation of the corner point is left at its original value.

Structure of the Elevation Data

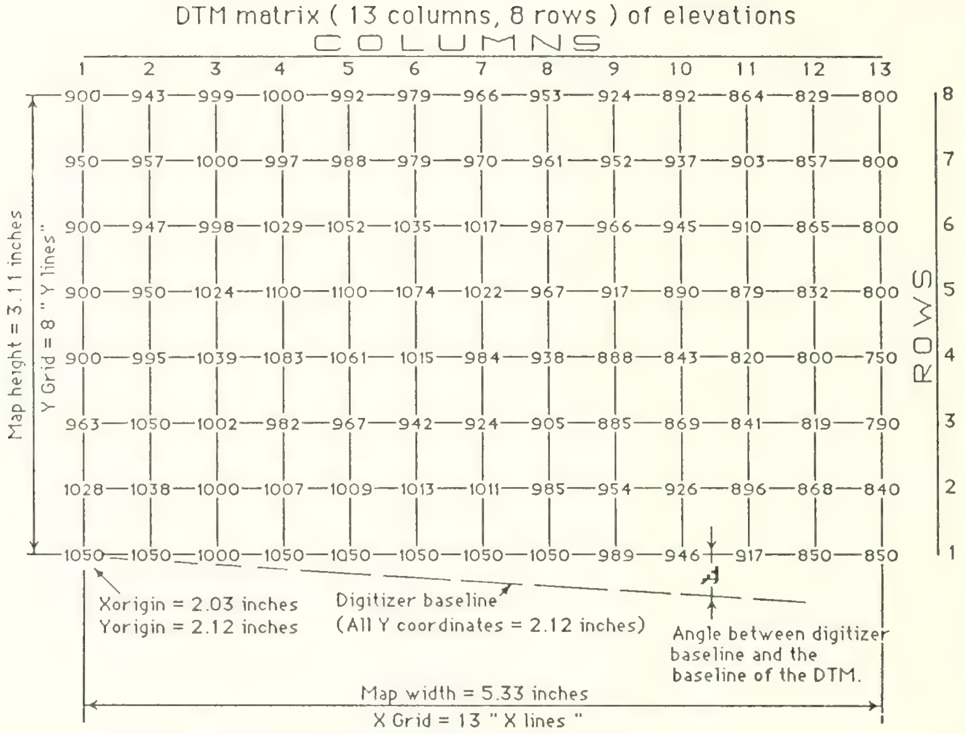
Once the interpolation processes are completed, each gridline-intersection point is assigned an elevation, and the DTM is stored in a data file. The calculated grid elevations are shown in figure 7. The original contour lines that the DTM was derived from are also shown to illustrate the change.



900	943	999	1000	992	979	966	953	924	892	864	829	800
950	957	1000	997	988	979	970	961	952	937	903	857	800
900	947	998	1029	1052	1035	1017	987	966	945	910	865	800
900	950	1024	1100	1100	1074	1022	967	917	890	879	832	800
900	995	1039	1083	1061	1015	984	938	888	843	820	800	750
963	1050	1002	982	967	942	924	905	885	869	841	819	790
1028	1038	1000	1007	1009	1013	1011	985	954	926	896	868	840
1050	1050	1000	1050	1050	1050	1050	1050	989	946	917	850	850

Figure 7—Grid-intersection elevations of the DTM as interpolated from digitized contour lines.

The DTM in figure 7 shows portions of the data required; it is an incomplete file included to illustrate the transition from contour-line map to gridded terrain data. The complete listing of the data stored in a DTM data file is shown in figure 8.



	1	2	3	4	5	6	7	8	9	10	11	12	13
8	900	943	999	1000	992	979	966	953	924	892	864	829	800
7	950	957	1000	997	988	979	970	961	952	937	903	857	800
6	900	947	998	1029	1052	1035	1017	987	966	945	910	865	800
5	900	950	1024	1100	1100	1074	1022	967	917	890	879	832	800
4	900	995	1039	1083	1061	1015	984	938	888	843	820	800	750
3	963	1050	1002	982	967	942	924	905	885	869	841	819	790
2	1028	1038	1000	1007	1009	1013	1011	985	954	926	896	868	840
1	1050	1050	1000	1050	1050	1050	1050	1050	989	946	917	850	850

Additional data required:
1. Scale of map in feet per inch
2. Contour-line interval in feet
3. Whether the DTM is a single unit or is part of a group of related DTMs covering a large and defined area

Figure 8—Site-specific numeric data that must be stored or calculated to provide a usable DTM for PLANS design programs.

The data list from figure 8 provides the variables needed to extract elevations from any digitized point on the planning area map via the following system: After the DTM is loaded into the computer, the user enters (by digitizing) the coordinates of the lower left corner (Xorigin and Yorigin) and the baseline (AngleA) of the DTM unit. This establishes the location of the DTM on the digitizer tablet and, along with the information loaded from the model's data file, is all that is needed to correlate the position of the digitizer cursor with the DTM on the topographic map. The coordinates (Xmap,Ymap) of any point digitized (Xi,Yi) on the map are calculated from the following equations:

$$\text{Xmap} = [(\text{Xi}-\text{Xorigin}) \times \text{cosine } A + (\text{Yi}-\text{Yorigin}) \times \text{sine } A\,] \times \text{map scale} \text{ ; and}$$

$$\text{Ymap} = [(\text{Yi}-\text{Yorigin}) \times \text{cosine } A + (\text{Xi}-\text{Xorigin}) \times \text{sine } A\,] \times \text{map scale} \text{ ;}$$

where Xi and Yi are digitized points inside the DTM border, expressed in inches, and map scale is expressed in feet per inch.

The topographic elevation of any point on the map of the DTM unit is calculated with a method that exploits the structure of the DTM elevation matrix. The elevation data are contained in the elevation matrix of the DTM, which in this example is a 13-row by 8-column matrix of 104 elevations. Each elevation applies to a discrete point on the map of the DTM; the point is expressed in terms of x and y coordinates, with the origin (x=0.00 and y=0.00) set at the lower left corner of the map. The **column and row position of the elevation in the matrix is keyed to its x and y coordinate position on the map.** The elevation matrix is uniformly spaced to cover the height and width of the map of the DTM unit. The elevation in the first row and the first column of the 13-row by 8-column matrix pertains to the grid-elevation point at the lower left corner of the digital terrain model, which is 1,050 feet. The grid-elevation point at the upper right corner of the DTM (800 feet) is recorded in the 13th row and the 8th column of the DTM matrix. In this manner, the location (x and y coordinates) of every elevation can be determined from the elevation's position in the matrix, the number of rows and columns in the matrix, and the height and width of the DTM unit. Organizing the elevation data in this manner saves storage space because the x and y position of each grid elevation point can be determined without storing the x and y values associated with each elevation point.

Elevation of Points Falling Within a Grid Cell

The planner using the DTM in PLANS design programs usually will have design control points falling at locations within a grid-cell rather than directly on the grid cell corner point. Elevations must be calculated for these control points whenever they are digitized from the map of the DTM or projected from the DTM. Each of these elevations is interpolated from the specific location within a grid cell. The basis for this interpolation is shown in figure 9.

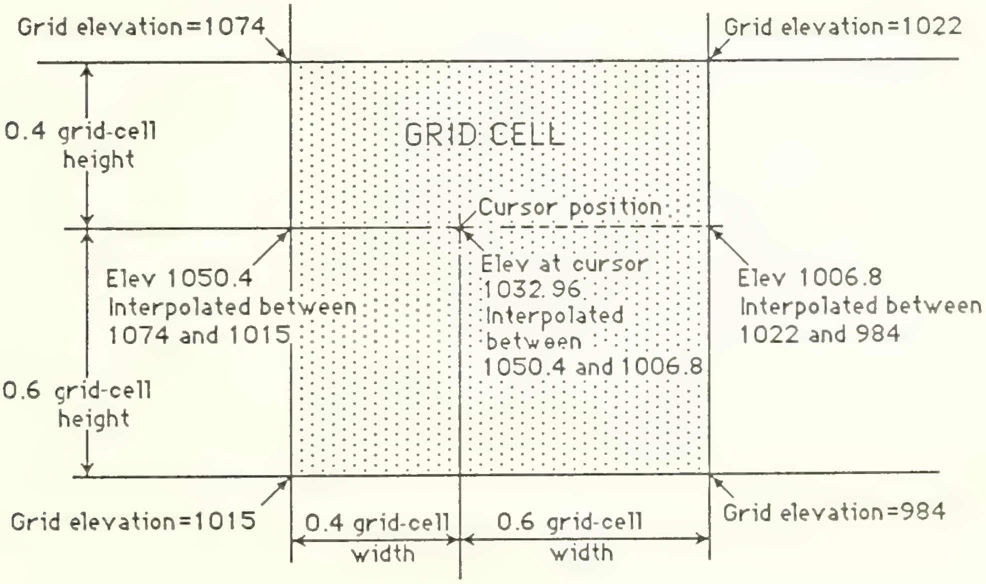


Figure 9—Interpolations used to solve for elevations within the grid structure.

The elevation of any point inside a grid cell is approximated using the three-step linear interpolation in figure 9. An alternate method of computing elevations bases the elevation of a point on the inverse of the distance squared of the point to the four grid-cell corner-point elevations. Lemkow (1977) compared the three-step linear interpolation with the inverse of the distance-squared method and found the three-step method was just as accurate; it also required only one-third the computational effort.

Technical inadequacies of the three-step interpolation method used in PLANS become minuscule when grid cells of the recommended size are established; but inadequacies do, nevertheless, exist. If all four corner elevations of a grid cell are on the same plane surface, the three-step method provides correct answers consistent with precise geometric solutions; however, three elevation points establish a plane, and it is unlikely that the fourth elevation point of a grid cell will fall on the same plane. Dividing the grid cell into two 45-degree triangles, each with three elevation points, will establish two planes. There are, however, two alternatives for this division. One alternative, which would improve the accuracy if a terrain divide (stream or ridge) ran between the lower left and the upper right corners of the grid cell, is to divide the grid cell into triangles in the upper left and lower right. The second alternative, which improves the accuracy when the terrain divide runs between the upper left and the lower right corners of the grid cell, is to divide the cell into triangles in the upper right and lower left. Use of the double-triangle approach did not appear to provide sufficient advantage to compensate for the increased complexity in problem formulation because terrain divides, when they occur within any grid cell, are random.

Spacing of Gridlines

Establishing a sufficiently fine spacing between gridlines is one important prerequisite to obtaining a DTM that corresponds well to actual terrain. The relation between grid spacing and accuracy must be understood by the user because the user controls grid spacing. The importance of this relation may be intuitively understood after examining perspective plots of two different DTMs. Both model the same topographic map; however, one of the DTMs has a spacing of 2 lines per map-inch (fig. 10), and the other (fig. 11) has a spacing of 10 lines per map-inch. The plotted, distorted squares are the individual grid cells. The digitized contour lines are also plotted on each figure.

If having the correct elevation at each grid-cell corner point is the established measure of DTM accuracy, then the DTM depicted in figure 10 is just as accurate as the DTM depicted in figure 11. But, if accuracy is defined as having a DTM that corresponds closely to the terrain being modeled, the DTM depicted in figure 11 is structured to be, and is, considerably more accurate than the DTM in figure 10.

Experience has led us to believe that spacings between gridlines of 0.07 to 0.15 map-inch are best for timber-harvest planning.

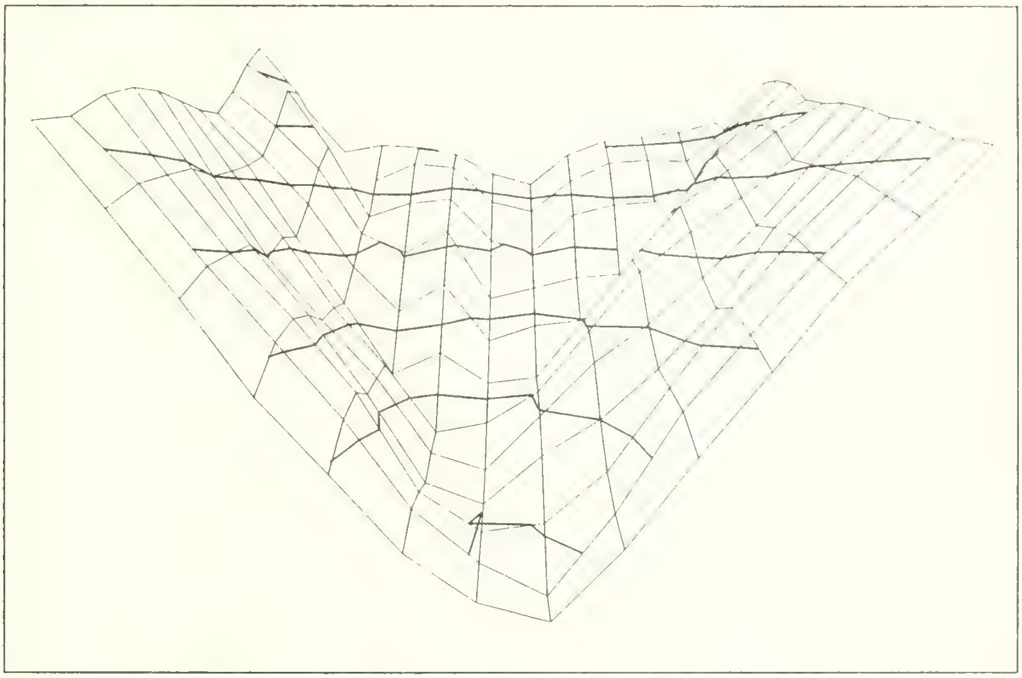


Figure 10—Perspective plot of a DTM ; the gridline spacing was set at 0.5 inch.

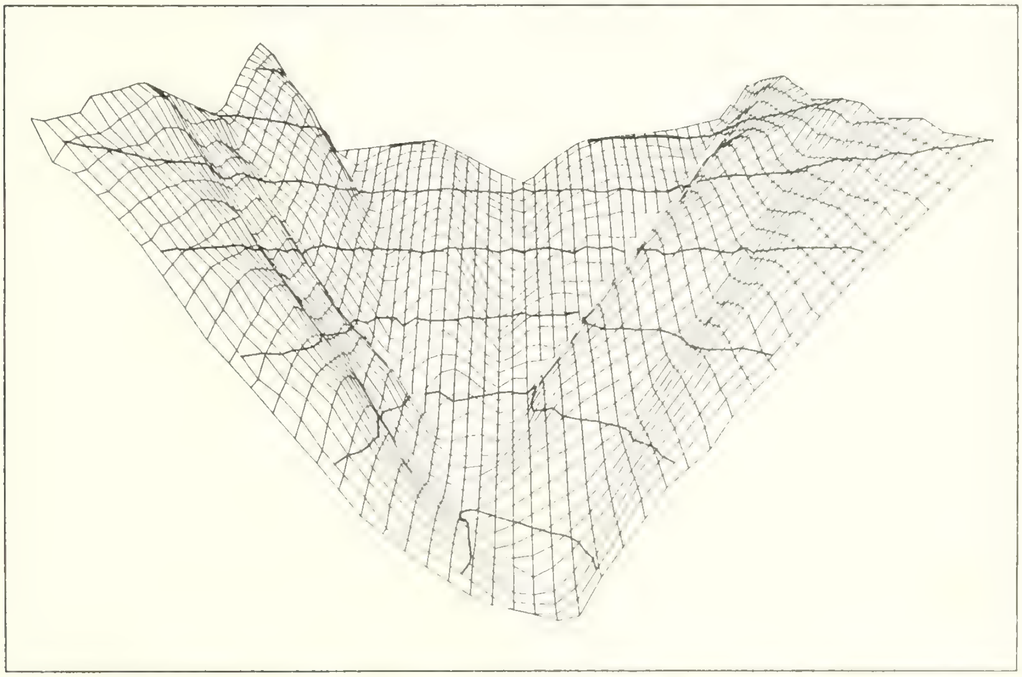


Figure 11—Perspective plot of a DTM ; the gridline spacing was set at 0.1 inch.

DTM Coverage for Large Planning Areas

The problem of integrating large planning areas with continuous and finely gridded DTM coverage requires special consideration in PLANS. The problem exists because:

1. DTMs cannot be created from map blocks (that is, input units) that are larger than the digitizer tablet; however, planning-area maps can be and often are larger than the digitizer tablet.

2. Even if the entire planning area fits on the digitizer, it still might be unwise to establish it as a single DTM input unit. DTM input units larger than 15 by 15 inches require an elevation grid that may be too coarse for planning purposes. The 15-inch dimension is because the widest spacing of gridlines advisable[2] for timber-harvest planning is about 0.15 inch, and a single DTM input unit cannot have more than 99 gridline spaces. The digitizer PLANS was developed on has an active surface area of 36 by 48 inches. Filling this active surface area with a single DTM input unit would result in a 0.48-inch gridline spacing, which is generally too coarse for good planning.

To circumvent these problems, the PLANS DTM approach provides for and recommends dividing large DTM coverage areas into smaller DTM input units. Figure 12 illustrates the recommended approach.

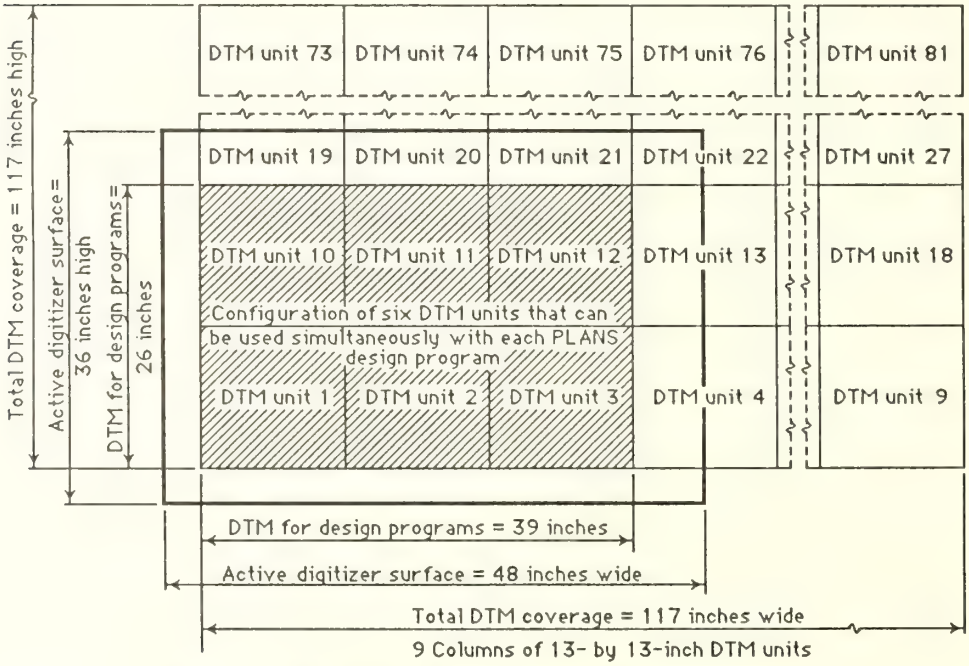

DTM unit 73
DTM unit 74
DTM unit 75
DTM unit 76
DTM unit 81
DTM unit 19
DTM unit 20
DTM unit 21
DTM unit 22
DTM unit 27
DTM unit 10
DTM unit 11
DTM unit 12
DTM unit 13
DTM unit 18
Configuration of six DTM units that can be used simultaneously with each PLANS design program
DTM unit 1
DTM unit 2
DTM unit 3
DTM unit 4
DTM unit 9
Total DTM coverage = 117 inches high
Active digitizer surface = 36 inches high
DTM for design programs = 26 inches
DTM for design programs = 39 inches
Active digitizer surface = 48 inches wide
Total DTM coverage = 117 inches wide
9 Columns of 13- by 13-inch DTM units

Figure 12—Arrangement of small, tightly gridded DTM input units that cover a large DTM area and provide a combined design DTM that uses the active digitizer space.

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[2] This recommendation of a 0.15-inch maximum gridline spacing is not absolute. Use of a very large-scale (1 inch=100 feet) planning map with widely spread contour lines would warrant a wider spacing between gridlines.

Each of the 81 DTM units indicated in figure 12 has to be created and processed individually; yet the units have a relational structure so they can be grouped to provide continuous elevation coverage over larger areas. The continuity is needed during the design phase because profiles and other design elements cannot be constrained to terminate at DTM-unit boundaries. The continuity is possible because of a provision for loading six DTM units into an enlarged DTM (shown in fig. 12 as a shaded area).

Even though the DTM coverage inferred in figure 12 is theoretically unlimited, it has practical limitations; for example, the handling of large topographic maps. Assembling and measuring large base maps requires careful drafting and handling (the appendix explains the problems and outlines a procedure for creating large DTMs). If the base map is divided to facilitate handling, the transfer of DTM-unit control points from the initial to the continuation maps must be precise. Slight differences in map size from one print to another can become critical. Errors in line projection increase in proportion to map size. These potential problems make it is advisable to restrict planning projects to manageable-size map areas.

Corrections to Border Elevations for Enlarged DTMs

The common elevations on the borders of DTM units are modified when the units are grouped into an enlarged (six-unit) DTM. Border elevations for one unit show the same points of actual terrain as do elevations for the adjacent unit, yet the figures are often contradictory. It is likely that neither is correct. This occurs because the boundary grid-point elevations are not interpolated from contour lines surrounding them on four sides, but are restricted to contour lines inside the DTM unit. This problem and the manner in which it is resolved are shown in figure 13.

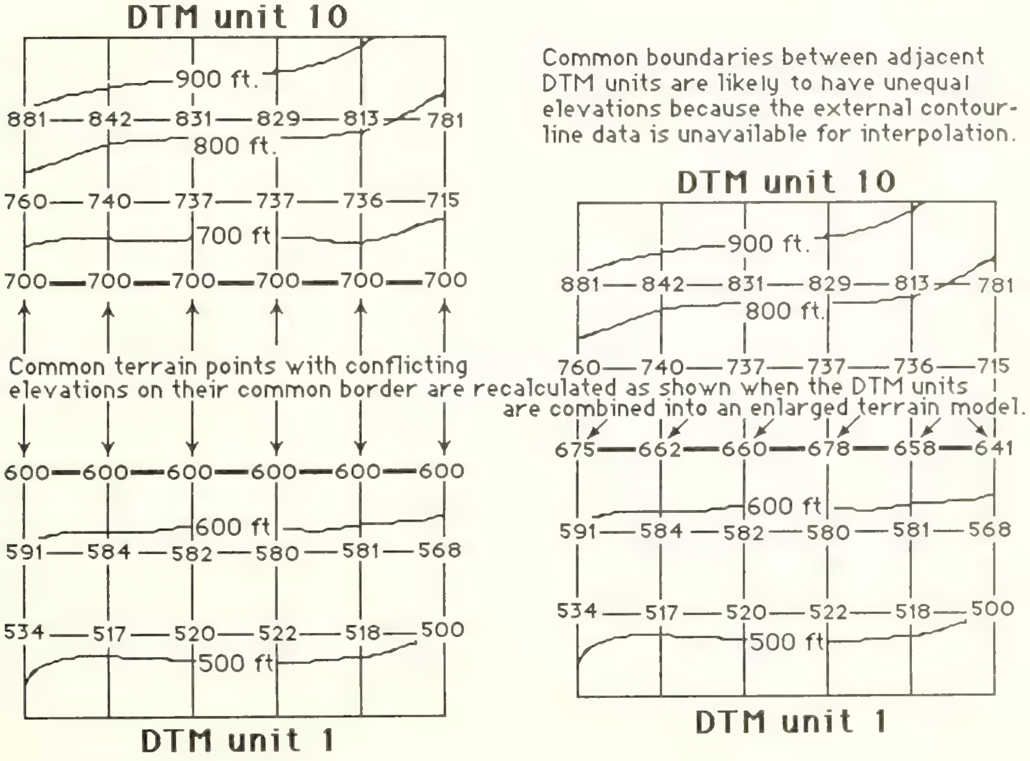

Figure 13—Adjacent, individually processed DTM units have incorrect and conflicting grid-point elevations for common border points. This error is corrected when the DTM units are combined into an enlarged DTM.

After the DTM block is loaded, the program simply calculates the common-border elevations as the numerical average of the elevations one grid row inside each of the adjacent DTM units.

Limitations of the MAP Program

The primary limitation of the MAP program is the accuracy, relative to the ground, of DTMs constructed with it. These DTMs are based on (constructed from) a topographic map of the planning area and are approximate representations of the topographic map. The topographic map is, in turn, an approximate representation of the ground. DTMs are thus distorted by two levels of error. A user of PLANS must learn how to restrict the error enough to provide an adequate basis for planning.

Discrepancies Between the DTM and the Topographic Map

Our design objective for the MAP program was to develop a gridded DTM that produced elevations for each point equal to what would be logically interpolated from the source topographic map (fig. 5). The basic design algorithm, though it substantially satisfies this objective, falls short of it in special circumstances. One example of this lapse can be seen in figure 14. No provision was made for incorporating point elevations into the DTM interpolation process. This is displayed by the grid points inside the 820-foot contour line. These grid points are labeled "820" feet in elevation.

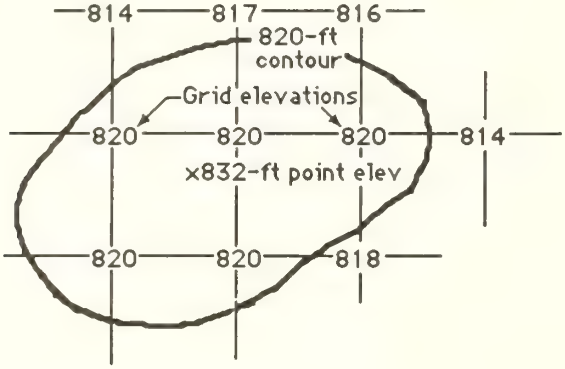

Figure 14—Point elevations on topographic maps are not taken into account when the grid elevations are calculated.

A map user seeing this type of contour-line configuration and a point-elevation label of 832 feet for an interior high point would know the grid elevations should actually be between 820 and 832 feet. A point-elevation interpolation procedure was deemed a minor omission because it would affect mainly areas on top of knobs and ridges where slopes are not generally severe and, therefore, would have minor impact on timber-harvest planning.

The second example of failure to meet our objectives for DTM building is shown by the elevation near the upper right center of figure 6 labeled "2d elev 799." A more correct interpolation of the elevation for that point on the topographic map is 804 feet. This example illustrates how an arbitrary elevation-correction algorithm that, in this case, interpolated a value of 799 between elevations of 795 and 807, can assign a grid-point elevation that is more in error than its initial, uncorrected elevation of 800 feet. This elevation-correction algorithm usually works well, and does more good than harm. Yet routines that rely on straight-line-interpolation algorithms cannot always provide solutions that fit natural slopes.

The two preceding situations, where the MAP program solves for values of grid elevations that are different from values attained by conventional interpolation [3/] techniques, normally affect a small portion of the elevation data in DTMs and do not invalidate the DTM as a basis for planning. A more fundamental difference between the DTM and the topographic map is the square grid structure of the DTM and the more correct curvilinear data structure of a topographic map. The grid structure of the DTM can, when the grid is correctly spaced, provide an adequate description of the topographic map and yet minimize the amount of terrain-description data that must be stored. As the grid spacing of the DTM decreases, the accuracy with which the DTM models the topographic map increases. Although it is not necessary to build DTMs with a tiny grid spacing to achieve usable terrain data, the relation cannot be ignored. Grid spacings of about 0.10 inch represent a reasonable compromise between an accurate depiction of the topographic map and a manageable amount of data.

A final factor influencing the fit between the DTM and the topographic map is the care and skill exercised by the user in digitizing contour lines. Errors made while tracing the contour lines with the digitizer cursor will be replicated in the DTM. This source of error has not, however, been a major problem.

DTMs may be obtained from several sources, but most of the widely available DTMs—such as the USGS DEM tapes and the DDTs from the U.S. Department of Defense—tend to fall unacceptably short of the MAP approach in accurately modeling a topographic map. DTMs from these sources are generally derived directly from aerial photogrammetry techniques that ignore existing mapping. These DTMs, when compared to existing maps, contain discrepancies that make them inadequate for planning. The inadequacy is not because the topographic map is necessarily more accurate than the DTM; it is because the planner, who views and is guided by the topographic map, is handicapped when using computer routines based on a distorted DTM. A few DEMs are being made by processes using digitized contour lines on existing maps. These DEMs, like the DTMs produced using MAP, yield a better fit between the resulting DTM and the topographic map.

Discrepancies between the topographic map and the ground—It is widely acknowledged that topographic maps often do not fit actual ground conditions. Topographic map error becomes more prevalent on maps made from aerial photos where the ground is obscured from the view of the stereoplotter operator by dense tree cover. Here, because the ground cannot be seen to be measured, a best guess at the ground elevation is made using the tree tops minus the assumed tree heights to establish the contour lines. The results are maps needed for timber-harvest planning being those most affected by discrepancies.

Topographic maps provide so much potentially useful information for preliminary planning and analysis that no real alternative to them exists. Two requirements for land management are to obtain adequate planning-area maps and to be aware of how to resolve the discrepancies between a map-based plan and the ground. Accurate topographic maps scaled at 1 inch to 400 feet with a 20-foot contour interval are recommended as a source of DTMs for PLANS.

[3/] In general practice, this is linear interpolation along a line as perpendicular as possible to the contour lines above and below the point the elevation is to be solved for.

Time Required To Construct DTMs With the MAP Program

Creating DTMs with the MAP program requires that some time and effort be expended to trace contour lines. A cost of $0.08 per acre for developing DTMs (for use in PLANS) by hand digitizing is reported by Twito and McGaughey (1984). This cost per acre will vary with the scale of the topographic base map, the number of contour lines, and the wage rate and ability of the person digitizing. The reported figure was based on a topographic map scale of 1 inch to 400 feet. The contour lines were digitized at a 20-foot interval over steep terrain. The wage rate was $12.00 per hour. The costs were based on a 3,200-acre planning project in the Cascade Range in Washington.

It should not take an experienced operator more than 4 hours to complete a DTM unit covering a 14-inch-square map section when the digitized contour lines are at 20-foot intervals and the terrain is mountainous. The process of building digital terrain models should be understood, but not necessarily performed, by the planner. Computer expertise and planning skills are not required for this work. What is needed are operators who are meticulous and thorough and who have good hand-to-eye coordination and a good understanding of contour maps.

Conclusions

The improved data-processing capability of current computer systems makes it an unnecessarily burdensome constraint to assemble slope and profile information on the basis of one input step producing only one elevation data point that can be used for just one design. Current computers can efficiently process designs related to the topography using DTMs. This capability has much to offer organizations that manage large areas of land because permanent DTM files of their holdings can be easily accessed for engineering designs and management information; consequently, there is increased interest in computer-based Geographic Information Systems (GIS), which include topographic (DTM) data. Adaption and use of PLANS constitutes, in one sense, an indoctrination to using a GIS because PLANS has specialized GIS characteristics tailored to designing timber-harvesting plans. The MAP program facilitates development of DTMs that will provide continuous topographic coverage of finely gridded elevation points at an easily justified price.

Operating Instructions and Worked Examples

An appendix to this report contains step-by-step operating instructions for the MAP program. A copy can be obtained on request (see the last page in this report). The appendix includes the following six examples that illustrate how the MAP program can be used:

1. Creating a new DTM.
2. Completing a partially completed and temporarily stored DTM.
3. Completing additional DTMs after the first DTM unit is finished.
4. Transferring DTM units between the hard disk and diskettes.
5. Correcting a DTM by redigitizing its incorrect portions.
6. Regridding a DTM unit from a file of contour lines.

All necessary topographic maps needed for these examples are included. The DTMs will be used in subsequent examples of related PLANS design programs.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter

Literature Cited

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Appendix

Recommended Approach for Building Large DTMs

Constructing large DTMs that have to be spliced (taped) together requires a reasonable amount of thought, care, and technique. Without these, time and effort may be wasted in an unsalvageable project. Certain principles that affect DTM fabrication from spliced contour maps should be kept clearly in focus to ensure success. The steps recommended here focus on techniques that can be applied by a typical engineering office.

1. Assemble and tape all topographic map sections into one composite map. See figure 15 for an example. The map sections may have to be assembled on an open floor space if the planning area is large. The composite map should have to be assembled only once. Not only is it inconvenient to repeat this step, but it is very difficult to reassemble the composite map to exactly the same dimensions as done initially, and a slight change in the dimensions of the tract can cause problems in the DTM building process.

2. Draw a straight baseline across the lower boundary of the area slated for DTM coverage.

3. Draw a straight line perpendicular to the baseline and extend it across the vertical length of the area slated for DTM coverage.

4. Carefully measure the total height and width of the DTM coverage area. These dimensions are both 117 inches in the example (fig. 15).

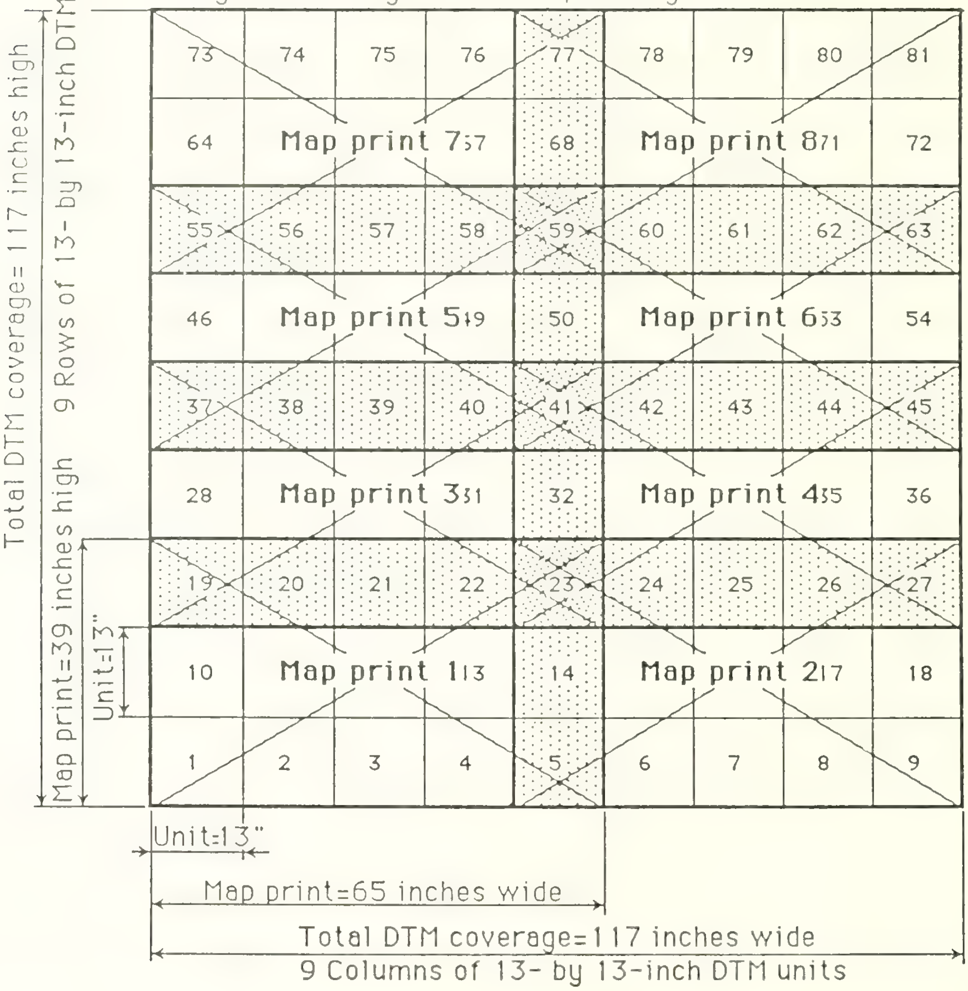
DTM input units that are shaded and on the adjoining boundaries of the map prints are duplicated on the adjacent map print for the purpose of providing DTM overlap and design continuity within the planning area.

Figure 15—Prints covering a large DTM can be established at a size that is easy to manage and can also provide for the duplication of DTM units needed for design continuity.

5. Determine the size of the DTM input units. The MAP program aids in this choice by displaying the DTM unit size and the arrangement that will provide the desired grid spacing. In the example (fig. 15), a minimum grid spacing of approximately 53 feet would be possible with a DTM unit size of 13 inches square at a map scaled 1 inch to 400 feet (that is, 13 inches x 400 feet per inch map scale ÷ 99 possible grid spaces per DTM unit = 52.53 feet).

6. Choose the best size of topographic map print, one that will be of manageable size and yet provide for full duplication of the DTM units that are on borders common to adjacent map prints. This point can be better understood after studying figure 15. DTM-unit duplication means, for example, that the top row of DTM units (19 through 23) on map print 1 must be the same as the bottom row of DTM units on map print 3, and so forth. This need for overlapping prints does not exist if a single print as large as the DTM coverage area can be managed. Of course in this example, a DTM coverage area would require one print of almost 10 feet by 10 feet—obviously not of manageable size. Many graphic reproduction labs, in fact, cannot process prints and Mylar reproductions larger than 25 square feet. The large, 46- by 58-inch board area of the digitizer (see Required Computer Hardware in Twito et and others (1987) used with the PLANS programs should permit use of a large print. The example assumes (and shows) map prints covering a 39- by 65-inch area to be of manageable size. Six DTMs covering an area 26 by 39 inches can be simultaneously loaded and used on the digitizer. The remaining portions of the print and the matching acetate overlay (see appendix in Twito and others 1987) can hang over the edges of the digitizer board.

7. Send taped DTM-coverage-area map to a graphics reproduction lab for photocopying new reproducible originals that correspond to the desired map-print coverage. These new originals will provide topographic map coverage of the planning area on conveniently sized prints. It is also important that these prints provide full DTM-unit overlap with a monolithic (unspliced) map sheet.

8. Begin DTM construction at the lower left corner of the DTM coverage area and complete the units in numerical sequence.

9. Transfer the boundaries of the completed units from one map print to the other using a light table. Any error in the original measurements of the DTM coverage area can, and will, shift the map location of the upper right corner of the DTM units and, eventually, the upper right corner of the coverage area. Slight shifting of these corners should be of minor consequence.

It may be worthwhile to use the MAP program to go through the entire boundary-transfer process (a dry run) without actually tracing the contour lines and completing the DTMs. If this proves satisfactory, the borders of the units will not have to be reestablished, and the contour lines can be processed on the second run.

An appendix to this report containing step-by-step operating Instructions for the MAP program is available on request from the Pacific Northwest Research Station. A copy of this appendix can be obtained by photocopying this page, filling in the necessary information, and sending it to:

USDA Forest Service
PNW Research Station
Forestry Sciences Lab
Forest Engineering Systems
4043 Roosevelt Way NE
Seattle, WA 98105 (206) 442-7814

This appendix includes examples of creating DTMs and demonstrates many of the options and manipulations that can be exercised during this process.

If you wish to receive the PLANS program set, which includes MAP stored on diskettes, enclose five 5¼-inch double-sided, double-density, flexible, mini discs.

Please send supplementary material for the MAP program to:

NAME ____________________

ADDRESS ____________________

____

CITY ____________________

STATE & ZIP CODE ____________________

Twito, Roger H.; Mifflin, Ronald W.; McGaughey, Robert J. The MAP program: building the digital terrain model. Gen. Tech. Rep. PNW-GTR-200. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

PLANS, a software package for integrated timber-harvest planning , uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. MAP, an integral program in the PLANS package, is used to construct the digital terrain models required by PLANS. MAP establishes digital terrain models using digitizer-traced contour lines from topographic maps, which are, in turn, processed into an elevation grid and stored in matrix form. MAP builds continuous digital terrain models that can cover large planning areas and builds them to any elevation grid spacing desired. Though the MAP method does not always result in digital terrain models that are a perfect equivalent to the topographic map, they should be adequate for planning. A guide giving detailed operating instructions for the programs is included.

Keywords: Timber harvest planning, computer programs/programing, models, logging operations analysis/design.

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EXAMPLE 1: CREATING A NEW DIGITAL TERRAIN MODEL

The planner wishes to construct a digital terrain model (DTM) from the contour map shown in figure 1. This DTM should be nearly identical to the DTM that is to be used in the other examples illustrating the PLANS design programs as it will be processed from the same contour map area. The map (fig. 1) should be taped to the digitizer tablet.

The DTM unit, for example 1, constitutes only one-quarter of the DTM coverage area, which encompasses four DTM units. The other three units are shown in figures 2, 3, and 4. Figure 5 shows all four units on one map at reduced scale. The boundaries of the DTM units have been marked on the figures, so the planner need not plot the DTM unit boundary for this example.

The planner accesses the MAP program by typing:
LOAD "PLANS/BEGIN:CS80,5",1 (followed by pressing the EXECUTE key)

Step 1-1

```
PLANS
PRELIMINARY LOGGING ANALYSIS SYSTEM

Please choose one of the following eight PLANS programs:
1. SKYMOBILE . . . .Analyze skyline payloads and spans for individual profiles.
2. SKYTOWER. . . . .Analyze payloads and spans for large central landings.
3. HIGHLEAD . . . . .Analyze direct pull and tightlining limits for highlead.
4. ROUTES . . . . . . .Project trial grade lines and calculate % sideslopes.
5. SLOPE. . . . . . . . .Plot overlay maps for areas of specified slope, aspect, etc.
6. VISUAL . . . . . . . .View a terrain model in perspective from desired viewpoint.
7. SIMYAR . . . . . . . .Simulate yarding activities to estimate yarding cost.
8. MAP. . . . . . . . . . .Digitize contour lines to create a digital terrain model.

Enter a 1 through 8 to match your choice.
```

Keyboard input: 8 (all keyboard inputs are followed by pressing the RETURN key)

comment: All the PLANS programs begin with this prompt. This response will initiate the building of a DTM by digitizing a contour map.

Step 1-2

You can now:

1. Create a new DTM unit by digitizing contour lines.
2. Continue digitizing a partially completed DTM unit.
3. Transfer stored DTM unit(s) between the disk and diskettes.
4. Redigitize part of an existing DTM unit.
5. Regrid a DTM unit from a contour-line file.

Enter a 1 through 5 to match your choice.

Keyboard input: 1

Step 1-3

Is this DTM unit part of a DTM coverage area that contains other previously completed (converted to gridded DTMs) units?

Enter (Y or N).

Keyboard input: N

Step 1-4

When selecting the size of the DTM unit be aware of the following:

-A DTM unit is limited to a 100 by 100 grid.
-Divide the map area for which you want DTM coverage into DTM units if you need good fit between the map and the DTM. This fit is more readily achieved with a tightly meshed elevation grid, which results from using smaller DTM input units.
-For example: DTM units 12" by 12" based on a 400 ft per inch scaled map permit an elevation grid spacing of .121 inches or 48.2 map scale ft., etc.
-Assuming the planning area is larger than the DTM unit, these DTM units can be combined into a 6 unit DTM block for use in the PLANS design programs. This DTM block can cover a map area 24 inches high by 36 inches wide.
-Combining adjacent DTM units into an enlarged DTM block permits planning harvest systems and features that overlap the DTM unit boundaries.

One unit input OK

Entire map will fit on digitizer. Grid spacing up to .45 of an inch is OK for this DTM unit. (or DTM is small enough for a sufficiently tight grid.)

Map too big for board

Map larger than digitizer. The area would have to be divided in any event.

Map fits-want tighter grid

Will fit but grid would be too coarse for desired accuracy.

PICK ONE OF THESE 3 CHOICES - press soft key

INPUT MAP IN ONE UNIT

MAP TOO BIG FOR THE DIGITIZER'S BOARD

MAP WILL FIT-SECTION TO TIGHTEN GRID

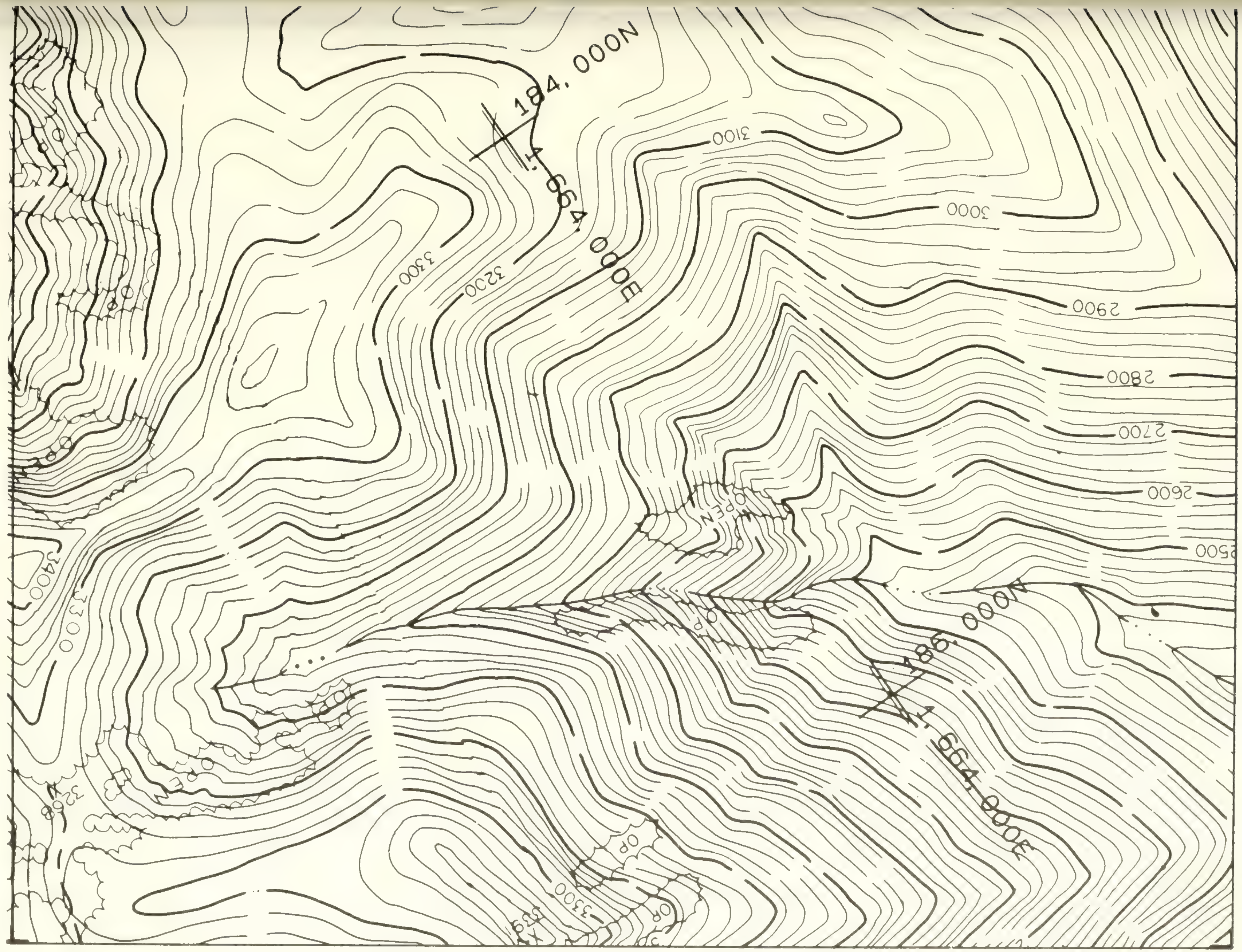


FIGURE 1. TEST_DTM1

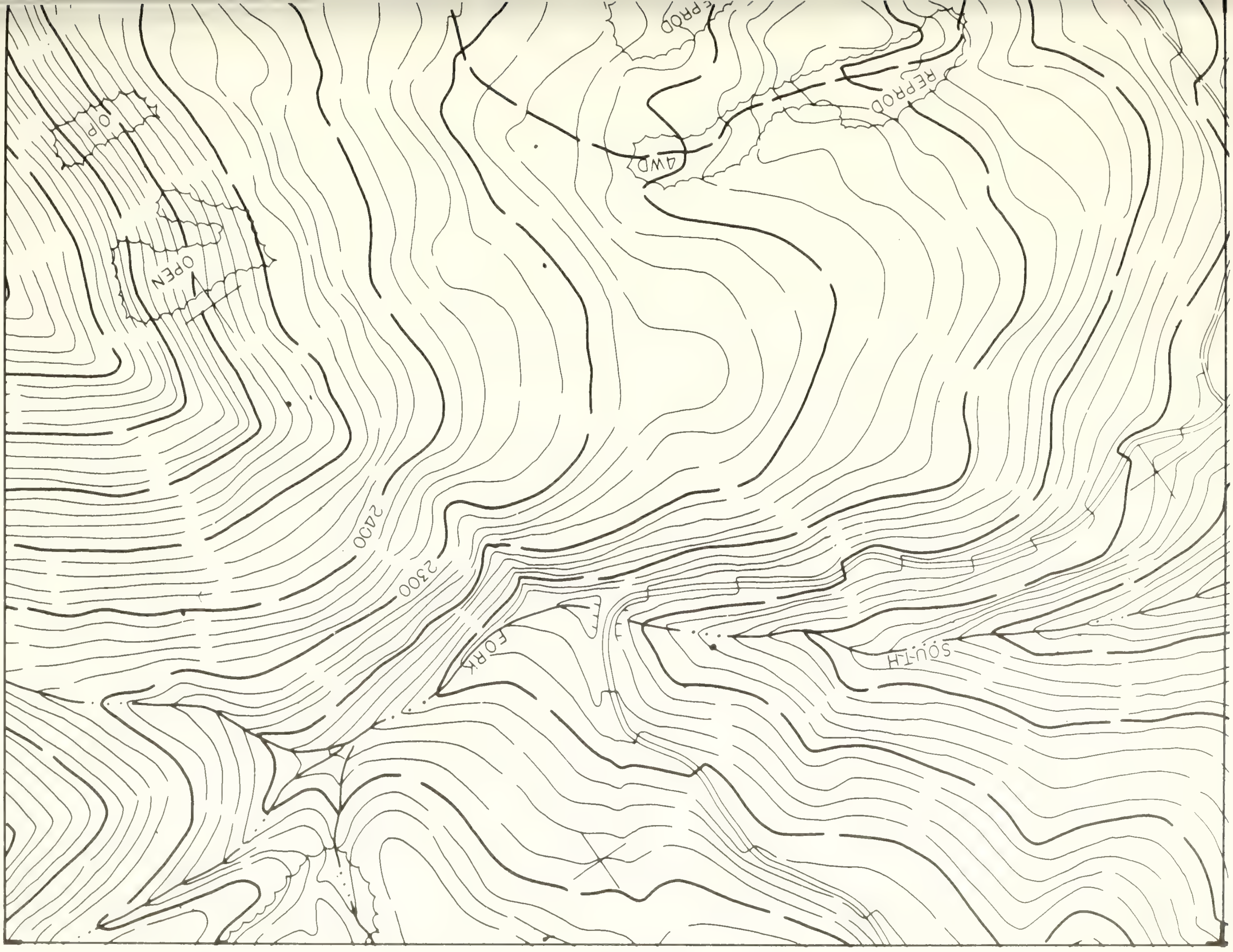


FIGURE 2. TEST_DTM2

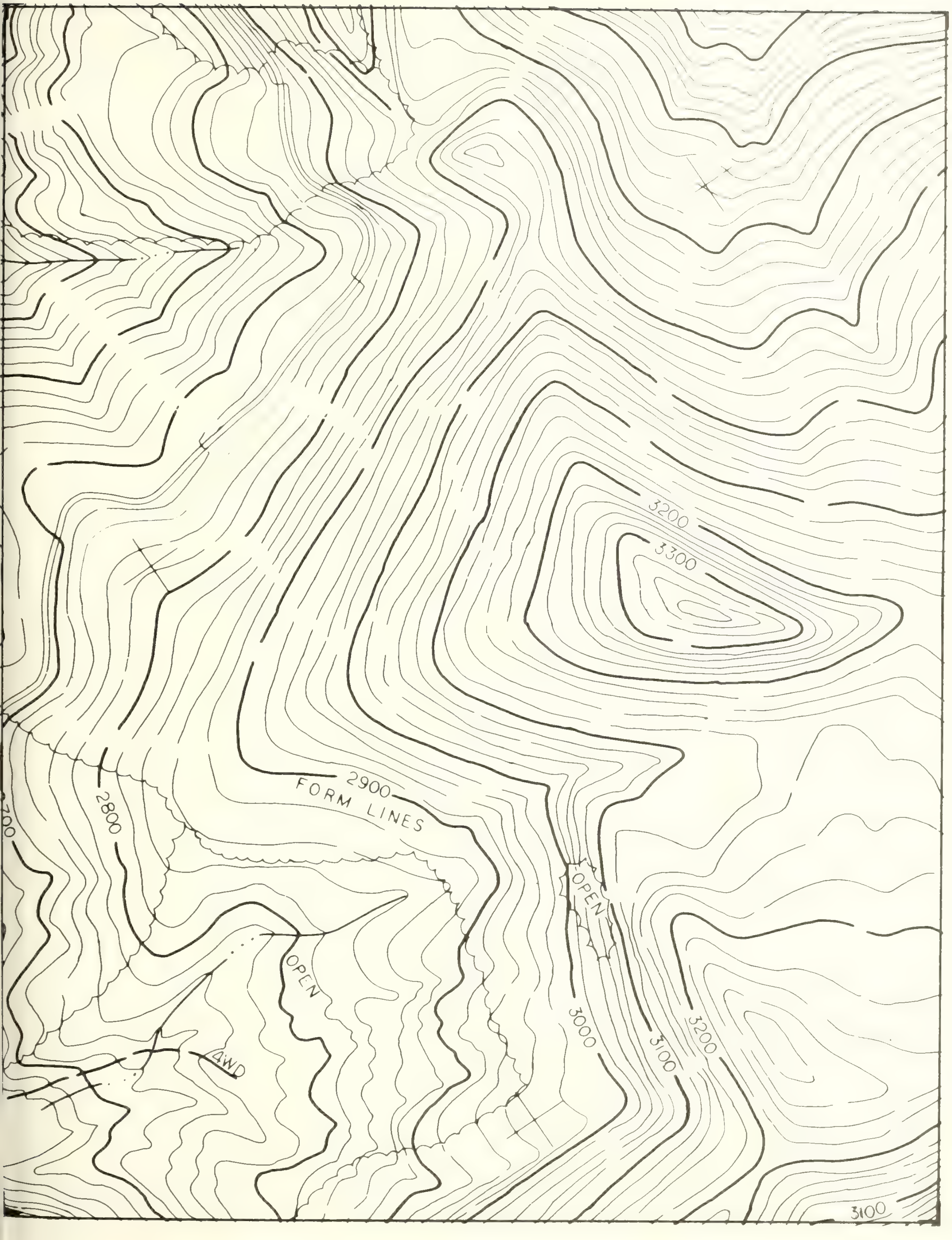


FIGURE 3. TEST_DTM3

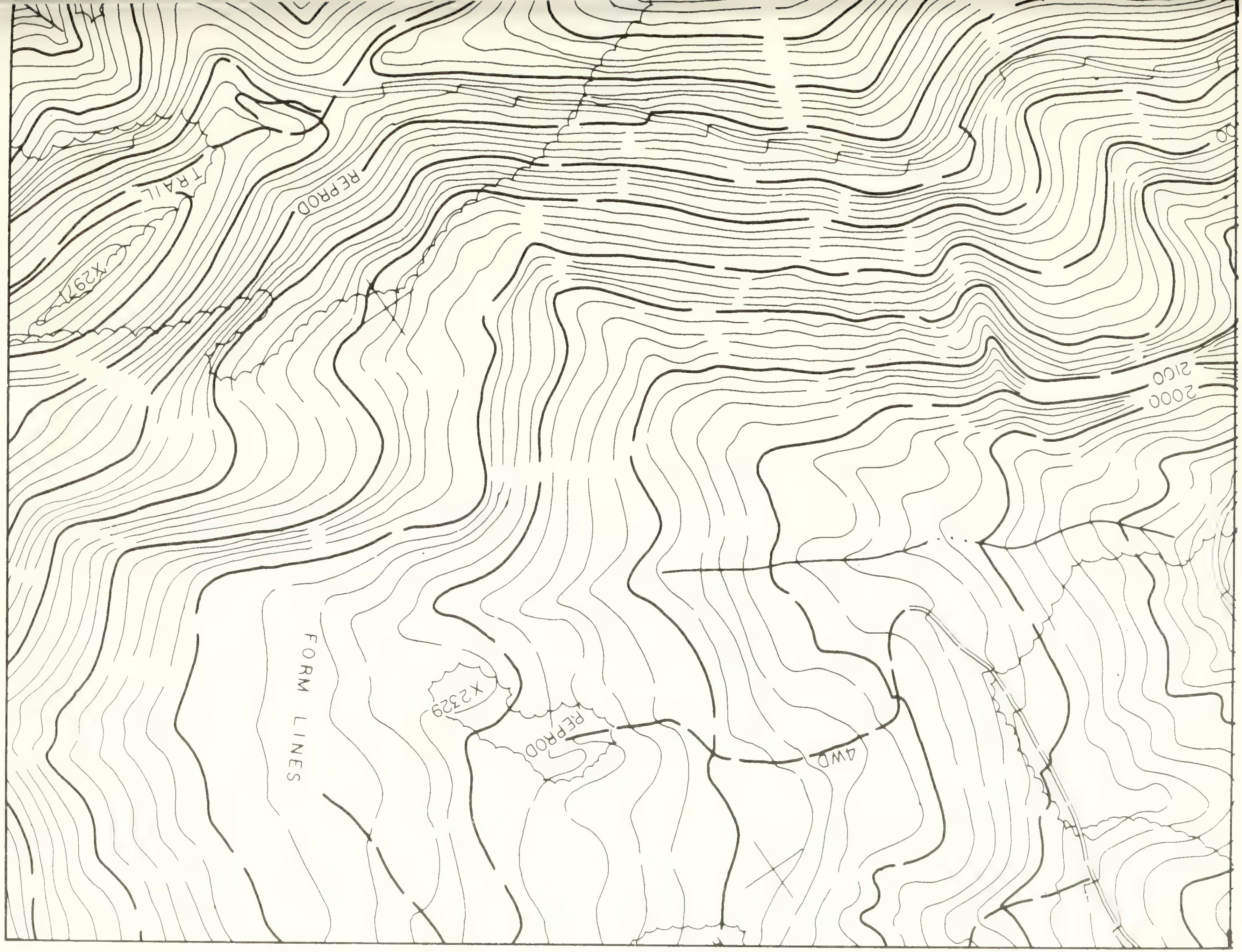


FIGURE 4. TEST_DTM4

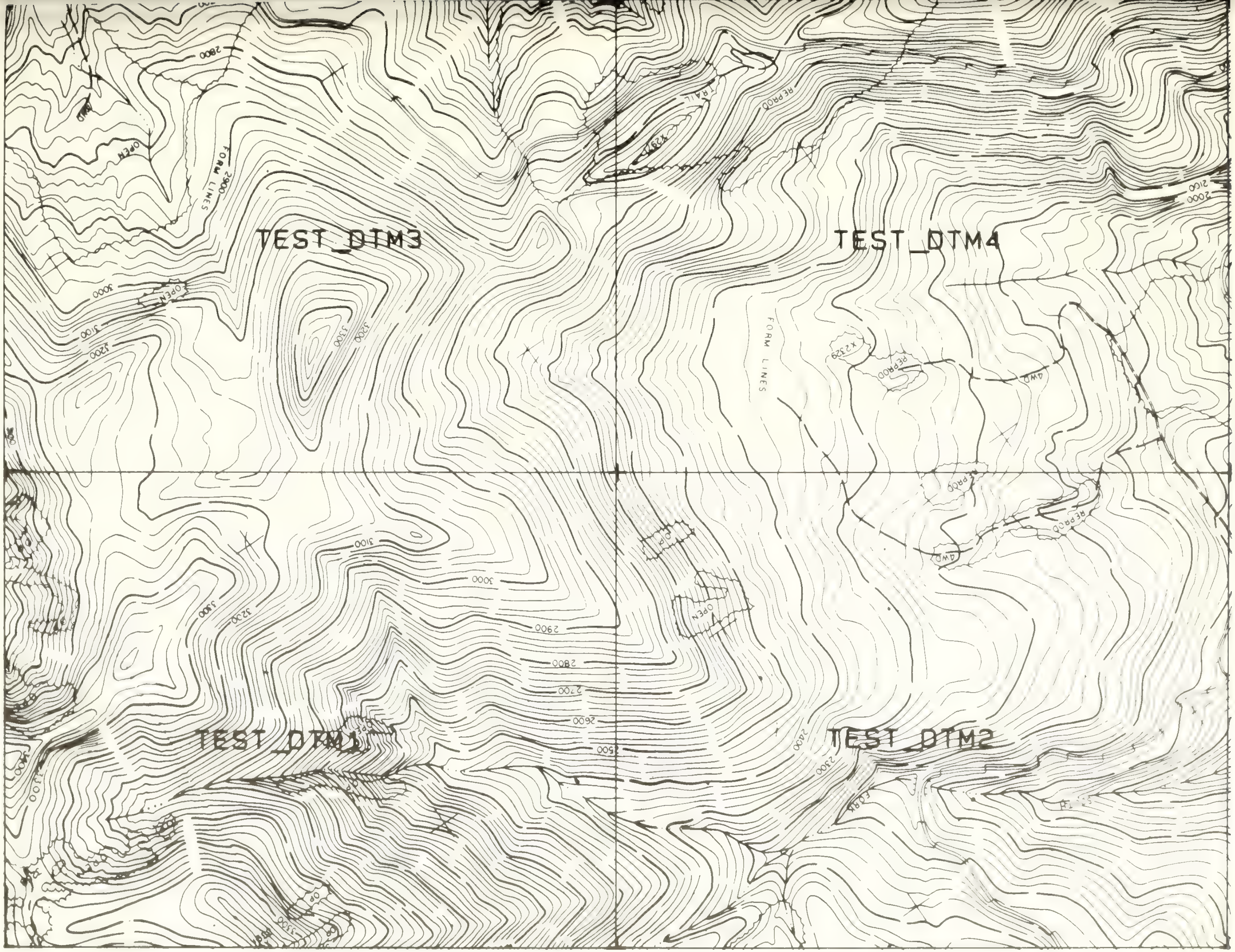


FIGURE 5. DTM COVERAGE AREA

Softkey input: ***MAP WILL FIT-SECTION TO TIGHTEN GRID*** ***(input by pressing softkey)***

comment: The finer grid requires no more effort to construct than a more open grid as contour lines are traced over the total area in either case. The finer grid does, however, enable the DTM to more closely approximate the terrain as represented by the contour map.

PRINTED INSTRUCTIONS:

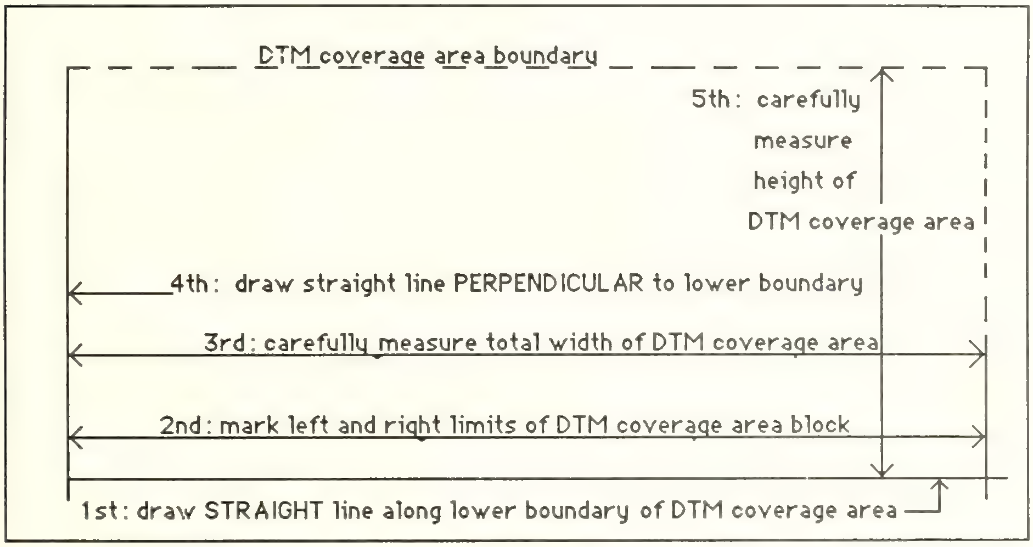
Since the DTM coverage area is too large to give the desired grid spacing, you must divide it into smaller units and input those a unit at a time.

First measure the size of the total DTM coverage area as shown on the hard copy below. This coverage area will be input in equal-sized units, which will give you the desired grid spacing.

DTM units can be loaded for design in groups of up to 6 units: (3 units wide by 2 units high) with the called unit at the lower left corner.

For now, one map print is needed on which the DTM coverage-area boundary can be marked as described below:

Step 1-5


DTM coverage area boundary
5th: carefully measure height of DTM coverage area
4th: draw straight line PERPENDICULAR to lower boundary
3rd: carefully measure total width of DTM coverage area
2nd: mark left and right limits of DTM coverage area block
1st: draw STRAIGHT line along lower boundary of DTM coverage area

Want a hard copy? YES enter Y, NO just press RETURN

Keyboard input: Y

Step 1-6

When the DTM coverage area boundary has been marked, press RETURN.

comment: No input instructions are provided for prompts that request a specific action and do not require entering variable data.

Step 1-7

Enter the width of the DTM coverage area (in inches).

Keyboard input: 18.00

comments: The example map is 18 inches wide by 14 inches high.

Step 1-8

Enter the height of the DTM coverage area (in inches).

Keyboard input: 14.00

Step 1-9

Enter the map scale (feet per inch).

Keyboard input: 400

Step 1-10

What spacing of the elevation-point grid do you want established for the DTM? (Enter in feet-map scale.)

Keyboard input: 50

comment: This value establishes the fineness of the grid and, consequently, the number of DTM units required to overlay the 18- by 14-inch DTM coverage area.

Entering a value of 50 feet will require that the DTM coverage area be input in four DTM units. A DTM unit is limited to a maximum of 100 vertical and/or horizontal gridlines, which equate to 99 grid spaces. The grid spacing on the map is 0.125 inch (50 feet/400 feet per inch map scale=0.125). It follows that the largest height or width a map can be to be entered in one DTM unit is 12.375 inches (99 x 0.125=12.375). The height and width of the DTM coverage area is 18 by 14 inches; therefore four DTM units (9 by 7 inches) will be needed to meet 50-foot grid-spacing requirements. Note that this is consistent with the response in step 1-4.

Step 1-11

The DTM coverage area can be divided into:

1. 1 unit with 72.7-foot grid spacing.
2. 4 units with 50.0-foot grid spacing.
3. 4 units with a minimum 36.4-foot grid spacing.
   or press RETURN to enter a new spacing.

Enter a 1 or 2 or 3 (or just RETURN) to match your choice:

Keyboard input: 3

comment: The resulting number of units needed to meet the requirements of a 50-foot grid spacing is four. Choice 3 calculates and offers the tightest grid possible without increasing the number of units required.

Because of the constraint of illustrating the various routines on publication-size maps, this example uses a tighter grid spacing (36.4/400=0.09 inch) than that proven convenient for normal applications.

Step 1-12

PRINTED INSTRUCTIONS:

The 18.00-inch by 14.00-inch DTM coverage area must be divided into 4 units, 2 horizontally and 2 vertically as shown below.

A data file will be created to store the DTM of each map unit. The name of the data file for storing the DTM will be in the following form:

1 to 12 characters + the number of the DTM unit (1 to 4).

Note: DTM units must be numbered left to right, bottom to top as shown in the diagram below. It is recommended that this print be saved and used as a record of which DTM units have been digitized and stored.

The first DTM unit to be digitized must be the lower left unit of the DTM coverage area and so must have the number 1 assigned to its name.

Each unit must be squared at 9.00 inches width by 7.00 inches height.

3	4
1	2

CRT PROMPT:

What is the character portion of the DTM unit name (1 to 12 characters)?

Keyboard input: TEST_DTM

Step 1-13

There is already a set of DTM units with the name: TEST__DTM containing 4 DTM units. Of the 4 units, 4 have been completed.

If you know the history of the existing DTM units (who created them, what area they represent, etc.) and know they are no longer needed, you can PURGE them.

However, if you are unsure of the DTM units' history, you should enter a new name for your DTM.

Or if DTM units are part of your own project, and somebody else completed them without your knowledge, you can complete the set of DTM units.

ENTER A NEW NAME FOR MY DTM UNITS	PURGE THE EXISTING DTM UNITS	COMPLETE THE SET OF DTM UNITS

Softkey input: PURGE THE EXISTING DTM UNITS

comment: Two files having the same name cannot be stored in the same directory. The CRT prompt above will only appear when it is needed to avoid duplication in file names.

The user is cautioned to use the purging (file erasing) option with care. Erasing DTM units constructed as learning exercises is a trivial matter, but erasing all the DTMs in somebody else's planning project is not.

If the user responded incorrectly in step 1-3 with a "N(o)" when other DTM units had in fact been completed, the "complete the set" option will provide a second chance to enter the correct "Y(es)" input at step 1-3.

Step 1-14

What is the number of the TEST__DTM DTM unit that you want to digitize?

Keyboard input: 1

comment: Always start with the lowest numbered DTM unit and complete the DTMs in ascending numerical sequence.

The common borders of adjacent DTM units must match without gap or overlap. Corner-projecting routines are used to locate the three remaining corners after the lower left corner and the unit's alignment are established by digitized input. The lower right corner of unit 1 must therefore be accurately established before the position of the lower left corner of unit 2 is known because they are common points.

Step 1-15

Digitize the LOWER LEFT corner of the DTM unit.

Digitizer input: ***1. Center the cursor over the lower left corner of the DTM unit.***
2. Press any cursor key.

Step 1-16

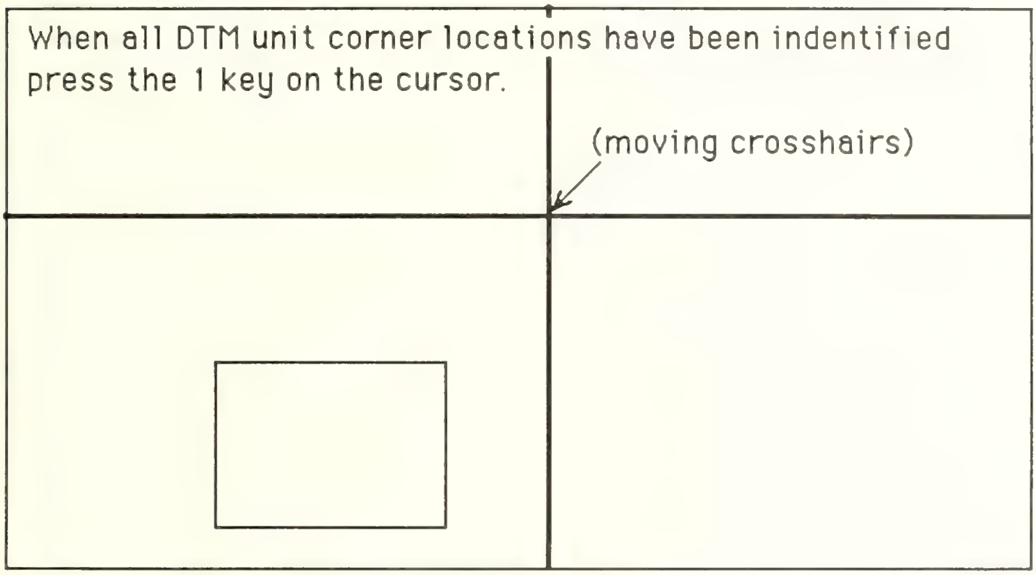
Digitize point on LOWER BOUNDARY of the DTM unit.

Digitizer input:* *1. Center the cursor on the lower boundary line of the DTM unit.
2. Press any cursor key.

comment: It is critical that the map not be shifted on the digitizer's surface until the digitizing of the contour lines is concluded.

Establish an accurate projection of the alignment of the DTM unit by digitizing a lower boundary point at least 9 inches, if possible, to the right of the lower left corner

Step 1-17



When all DTM unit corner locations have been indentified press the 1 key on the cursor.

PRINTED INSTRUCTIONS:

-Pressing the 1 key on the cursor terminates this process. Do not press it until all the corners have been marked as detailed below.
-Move the cursor until a DTM unit corner is found (a beep will sound). The proximity of the cursor to the corner can be gauged on the CRT, and corner locations may be found in any order.
-Mark the location on the map.
-Check the accuracy of the mark by positioning the cursor on it. If a steady beep does not sound, the corner must be remarked and rechecked.
-Draw lines to connect the corners of the map.

Digitizer input: After all the corners have been found, marked, and checked, press the 1 key.

comment: If this procedure is carelessly done, the common border lines between adjacent units will develop gaps or overlaps during the DTM construction process. The potential for this type of error increases for large DTM coverage areas that require many DTM units.

Step 1-18

A DIGITIZER MENU will be required for program control. Do you need a plot of this menu?

(Y or N)

Keyboard input: Y

comment: The user will direct the various phases of DTM building by using the cursor as a pointer and digitizing the appropriate menu selection.

Step 1-19

This menu will be plotted on the 7580B DRUM PLOTTER.

Load it with an 8- by 11-inch minimum-size sheet.
When ready, press RETURN.

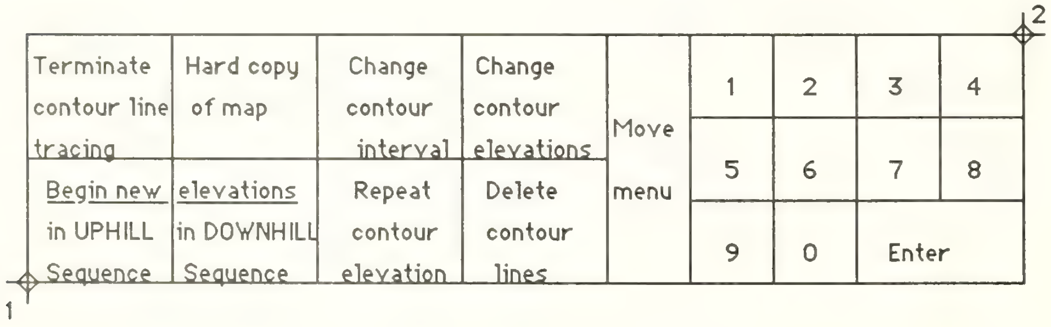
Step 1-20

Attach the menu to the digitizer, aligning its edges parallel with the digitzer's active surface boundary, then press RETURN.

comment: The menu should be horizontally aligned with the digitizer base.

Place the menu anywhere on the active surface of the digitizer outside the DTM unit.

Menu plot:


2
Terminate contour line tracing
Hard copy of map
Change contour interval
Change contour elevations
Move menu
1
2
3
4
5
6
7
8
Begin new in UPHILL Sequence
elevations in DOWNHILL Sequence
Repeat contour elevation
Delete contour lines
9
0
Enter
1

Step 1-21

Digitize the menu corner labeled '1' by pressing any cursor key.

Step 1-22

Digitize the menu corner labeled '2' by pressing any cursor key.

Step 1-23

Enter the starting contour elevation in feet from the keyboard.

Keyboard input: 3420

comment: The user can begin tracing the contour lines of the map at any location within the DTM unit. A good method is to begin contour-line input at the highest contour line and work downhill, or vice versa.

Step 1-24

Enter the contour interval in feet from the keyboard.

Keyboard input: 20

comment: At times a user may enter 100 and digitize only the major, labeled contour lines when a less accurate DTM suffices.

Step 1-25

The elevation of each subsequent contour line will automatically:
1. Increase 20 feet.
2. Decrease 20 feet.
Enter a 1 or 2 from the keyboard to match your choice.

Keyboard input: 2

Step 1-26

```
PRESS 1 BUTTON ON CURSOR THEN TRACE YOUR 3420 FT CONTOUR LINE : MODE DOWNHILL
```

comment: 1. Center the cursor crosshairs on the contour line slightly outside the DTM unit's boundary.
2. One press of the cursor's "1" key activates the contour-line digitizing routine.
3. Hold the cursor in two hands. Keep the crosshairs on the contour line as you move the cursor along the contour line to its entry into the DTM unit, along its route through the DTM unit, and past the point where it exits the DTM unit.
4. As each contour line is traced by the cursor, it is plotted on the CRT. A beep sounds when the contour-line trace exits the DTM unit. This beep means the digitized input stops until the next contour line is initiated.
5. The procedure is similar for tracing contour lines that are entirely inside a DTM unit. Then, however, a beep sounds when the contour line has been traced back to its beginning point. If an internal contour line does not loop back to its beginning point it must be terminated by pressing the cursor's "1" key at the end of the contour line.
6. Long contour lines will be automatically terminated if the file space allotted for one contour line becomes filled with digitized coordinate data. When this happens, move the cursor to where the line's plot stopped, press the "1" key, and continue tracing the line to its completion (DTM unit exit or closure). The CRT plot showing the position of the cursor and the end of the terminated contour line provide the visual prompt needed for contour-line continuation.

Digitizer input: ***1. Center cursor on the 3,420-foot contour line just outside the DTM unit boundary.***
2. Press the "1" key on the cursor.
3. Trace the contour line into the DTM unit and continue tracing it until it exits the DTM unit.

PRINTER OUTPUT:

Contour Line No.	Elevation (feet)
1	3420

comment: As each contour line is completed, its line number and elevation is printed. This verification should be used to check and, if need be, correct false entries.

Step 1-27

comment: Use the digitizer menu operations while digitizing contour lines to complete a DTM unit. The step format resumes on page 24 and is incorporated into the explanation of the menu selection item: "Terminate contour-line tracing."

DIGITIZER MENU OPERATIONS

comment: The function of each menu selection is explained under the underlined headings that follow. These should be studied before you begin digitizing contour lines. There is no one absolute and correct sequence of use for menu operations. Understanding the purpose and function of each menu operation will, however, enable you to contrive a sequence of menu operations that will give you a correctly digitized DTM unit.

The menu selections are made by digitizing the appropriate menu block. Never try to make a new menu selection when you are tracing a contour line with the digitizer. Wait until the line is finished.

Begin new elevations in UPHILL or DOWNHILL sequence

Digitizer input: ***1. Center cursor crosshairs on the appropriate menu block for UPHILL or DOWNHILL sequence.***
2. Press any cursor key.

Enter the contour elevation (feet) by first digitizing the number squares on the menu, then the 'Enter' rectangle.

Digitizer input: Digitize square "3"; square "4"; square "2"; square "0"; and square "Enter" to commence with elevation 3420.

comment: These are the most frequently used menu selections in DTM building. Each successive contour line is automatically assigned an elevation one contour interval higher (if uphill sequence is in effect) or one contour interval lower than the elevation of the previous contour line.

When the user wants to digitize the contour lines by working uphill, the "Uphill sequence" mode should be selected. When working downhill, use the "Downhill sequence" mode. "Uphill sequence" remains in effect until "Downhill sequence" is pressed, and vice versa.

The incrementing (or decrementing) of elevations between successive contour lines is temporarily suspended for long contour lines that are automatically ended when their file space is filled. The next contour line (which must be started at the end point of the long contour line) is automatically assigned the same elevation as its predecessor. The uphill or downhill mode automatically resumes after the "tag on" contour line is completed (by DTM unit exit or contour-line closure).

The user may want to remain in the current uphill (or downhill) mode but move to another series of contour lines requiring an elevation change; in this case, the user should digitize the uphill (or downhill) sequence block on the menu and enter the new starting contour-line elevation.

Repeat contour elevation

Digitizer input: ***1. Center cursor crosshairs on the Repeat contour elevation block.***
2. Press any cursor key.

comment: This menu selection permits the user to label and store the next contour line at the same elevation as the line that preceded it.

This option can be useful for continuing contour lines that exit and reenter the DTM unit.

Change contour interval

Digitizer input: ***1. Center cursor crosshairs on the Change contour interval block.***
2. Press any cursor key.

Enter the contour interval (feet) by first digitizing the number squares on the menu then the "Enter" rectangle.

Digitized input: Digitize: square "1"; square "0"; square "0"; and square "Enter" to enter a contour interval of 100.

comment: Sometimes a user may accept zones within the DTM of reduced accuracy if the DTM can be developed with, commensurately, less effort. Digitizing only the darker, labeled (boss) contour lines provides for this compromise. The user can enter the contour interval matching the elevation between the boss contours and digitize just those contour lines. Automatic incrementing or decrementing elevations to match the boss contour lines will expedite the process.

Change contour elevations

Digitizer input: ***1. Center cursor crosshairs on the Change contour elevation block.***
2. Press any cursor key.

You can change the elevation of:

1. A single contour line.
2. Any number of consecutive contour lines.

Enter a 1 or 2 from the keyboard to match you choice.

Keyboard input: 1
Enter the contour line number from the keyboard.
Keyboard input: 11
The old elevation for contour line 11 was 3200 feet.

Enter the new elevation in feet from the keyboard.
Keyboard input: 3220
Printer output:

```
Contour   Elevation
Line No.  (feet)

11        3220 (changed)
```

If Keyboard input: 2
Enter the starting contour line number from the keyboard.
Keyboard input: 5
Enter the ending contour line number from the keyboard.
Keyboard input: 10

Contour line elevations will be:
1. Automatically incremented
2. Set manually for each contour line.

Enter a 1 or 2 from the keyboard to match your choice.
Keyboard input: 2
The old elevation for contour line 5 was 3320 feet.

Enter the new elevation in feet from the keyboard.
Keyboard input: 3340

comment: These input requests are repeated for contour lines 6 through 10.

Printer output:

```
Contour   Elevation
Line No.  (feet)

5         3340 (changed)
6         3320 (changed)
7         3300 (changed)
8         3280 (changed)
10        3260 (changed)
```

comment: This menu selection option allows users to correct the elevation on any contour line.

Delete contour lines

Digitizer input:* *1. Center cursor crosshairs on the Delete contour lines block.
2. Press any cursor key.

You can delete:

1. The last contour line.
2. A single contour line.
3. Any number of consecutive contour lines.

Enter a 1, 2, or 3 from the keyboard to match your choice.

If Keyboard input: 1

Printer output:

Contour Line No.	Elevation (feet)	
5	DELETED	-if the last contour line entered was 5

If Keyboard input: 2
Enter the contour line number from the keyboard.
Keyboard input: 4
comment: The output would be similar to the preceding example, except contour line number 4 would be deleted.

If Keyboard input: 3
Enter the starting contour line number from the keyboard.
Keyboard input: 1
Enter the ending contour line number from the keyboard.
Keyboard input: 5
comment: The output would be similar to the preceding example, except contour lines numbered 1 through 5 would be deleted.

Move menu

Digitizer input:* *1. Center cursor crosshairs on the Move menu block.
2. Press any cursor button.

Move the menu to a new location, aligning its edges parallel with the digitizer's active surface boundary, then press RETURN.

Digitize the menu corner label '1' by pressing any cursor key.

Digitize the menu corner label '2' by pressing any cursor key.

comment: The menu can be moved at any time, to any location on the active surface of the digitizer. Always place the long axis of the menu parallel to the horizontal axis of the digitizer.

Hard copy of map

Digitizer input: ***1. Center cursor crosshairs on the Hard copy of map block.***
2. Press any cursor key.

comment: The picture on the CRT of the contour lines traced is copied by the printer.

Terminate contour line tracing

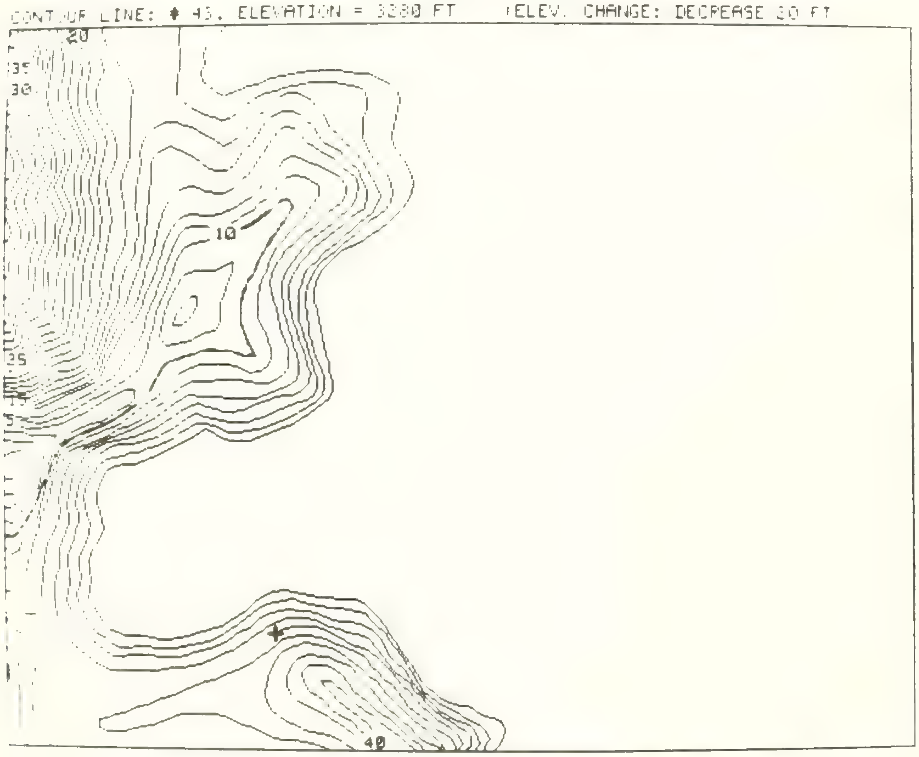
Digitizer input: ***1. Center cursor crosshairs on the Terminate contour line tracing block.***
2. Press any cursor key.

Step 1-28

comment: When the user wants to end the contour-line digitizing process, the "Terminate contour line tracing" option must be selected. This suspends additional menu operations.

It is not necessary to have all the contour lines that will constitute the final DTM unit digitized when this selection is made. This example shows a case where digitizing is terminated before all the contour lines of the map were digitized.

CRT status when Conclude digitizing is selected



```
CONTOUR LINE: # 43, ELEVATION = 3280 FT     (ELEV. CHANGE: DECREASE 20 FT
```

comment: The CRT picture shows the number of contour lines that were traced and stored when the digitizing was terminated. A hard copy of this is automatically printed for the user's future reference in step 1-31.

CRT prompt:

The DTM unit you have been digitizing is now:

1. Completed (i.e., all contour lines have been digitized) and will be converted to a gridded digital terrain model now.
2. Partially completed and will be stored on disk (or diskette) so that further digitizing can be continued later.
3. Partially completed and will be stored for further digitizing and converted to a gridded digital terrain model now.

Enter a 1, 2, or 3 from the keyboard to match your choice.

Keyboard input: 2

comment: Entering a value of "3" would be applicable if the user wanted to build a DTM unit by tracing only the boss contour lines and reserve the option of improving the accuracy of the DTM by digitizing the remaining contour lines later.

This option might also be used if a DTM unit is needed immediately for logging system analysis over a portion of the total area of the DTM. The user can complete the rest of the DTM unit when it is needed.

Step 1-29

It is possible to STORE CONTOUR LINE INPUT DATA onto the H.P. 7908 tape drive. From this data, the traced contour lines can be plotted and errors checked against the original map. Saving this DTM source data can provide the needed data for other DTMs of varying grid or structure to be processed at a later date WITHOUT RETRACING THE CONTOUR LINES.
If you want to STORE this data on tape, you'll need an INITIALIZED magnetic tape for STORING CONTOUR LINE DATA.

Would you like to store the traced contour lines on magnetic tape? (Y or N)

Keyboard input: Y

comment: This step ensures that the digitized contour lines will not have to be redigitized to produce DTMs needed for different applications. The digitized contour lines constitute a data source from which the gridded PLANS DTM is processed. Other DTMs for other applications such as PERSPECTIVE PLOT can be processed from this data source. Although the other DTMs could conceivably be reprocessed from the gridded PLANS DTM, special conversion programs would be needed, and the accuracy would still suffer. Saving original input data when it is feasible to do so is a good practice.

Saving digitized contour lines does require a large amount of magnetic storage space. A 16-megabyte backup tape on the H.P. 7908P tape/disc drive should provide enough space for approximately 40 DTM units, assuming approximately 240 contour lines are required per DTM unit.

Step 1-30

INSERT A TAPE CARTRIDGE IN THE H.P. 7908 DISC DRIVE, THEN PRESS RETURN.

comment: If RETURN is pressed before the BUSY light on the tape drive goes out, the following message is displayed:

WHEN TAPE IS INSERTED, WAIT UNTIL THE BUSY LIGHT GOES OUT, THEN PRESS RETURN

Step 1-31

```
:CS80,5,1
LABEL:
FORMAT: SDF
AVAILABLE SPACE: 15464
                              SYS  FILE    NUMBER   RECORD     MODIFIED         PUB  OPEN
FILE NAME              LEV   TYPE TYPE    RECORDS  LENGTH  DATE          TIME   ACC  STAT

PANTHER_CREEK1RC         1   9000  BDAT       300     1608  17-DEC-84   08:30   MRW

** STAND BY            ARCHIVING CONTOUR LINES            STAND BY **
```

comment: This catalog listing shows other contour-line files that have been stored on the magnetic tape. It will remain on the CRT until the current contour lines have been stored. This may take up to 5 minutes.

A hard copy of the traced contour lines (see step 1-28) is printed prior to storing the partial DTM unit on the H.P. 7908 hard disk.

There is space alloted on the hard disk for storing just one partial DTM unit. When contour-line digitizing is resumed on that partial unit, the space on the hard disk is freed for storing a different partial DTM unit. Partial DTM units require considerably more storage space than completed, gridded DTMs. The limit (one partial DTM unit) was set to ensure that excessive amounts of disk storage space are not consumed. It is assumed that once a partial DTM unit is stored, it will be finished before there is a need to store a different partial DTM unit.

If, however, a user should try to store a partial DTM unit when another partial unit already resides on the hard disk, the following salvage method is provided.

CRT PROMPT:

You cannot store this partial DTM on the main hard disk (:CS80,5). Space is allotted for one partial DTM on the main disk, and there is one there now.

But not to worry—your partial DTM can be stored on a diskette. You will need a blank initialized diskette for this.

Put a blank diskette in the internal drive. If it has not been initialized, you may do so now.

DO YOU WANT THIS DISKETTE INITIALIZED? (ENTER Y OR N)

comment: From this point, the partial DTM unit can be stored on the diskette. Regardless of whether the partial DTM unit was stored on the disk or on a 5-1/4-inch diskette, the program sequence is the same for the next step.

Step 1-32

comment: After the partially completed DTM is stored, the program recycles to step 1-1. Generally the user would stop using PLANS at this point, though the prompt permits continued use of other PLANS programs.

To clear the H.P. 9020 for use of different programs other than PLANS: type SCRATCH A, and press EXECUTE.

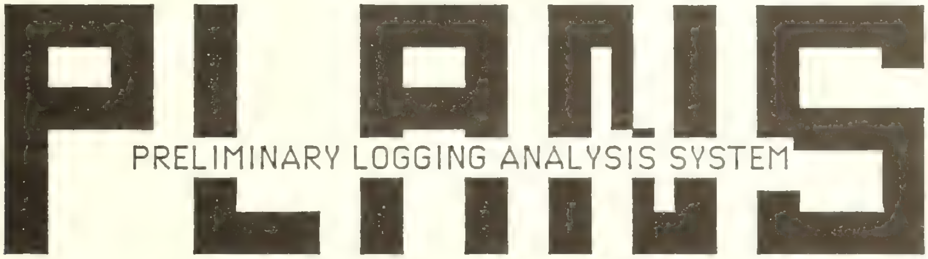
To shut down, simply turn off the power switches for the H.P. 9020 and peripherals.

EXAMPLE 2: COMPLETING A PARTIALLY DIGITIZED DTM

The planner wishes to complete the TEST_DTM1 unit. Contour-line digitizing was started on this DTM unit in example 1, but digitizing was concluded before all the contour lines were digitized, and it was stored as a partially completed DTM unit.

The planner again accesses the MAP program by typing:
LOAD "PLANS/BEGIN:CS80,5",1 (followed by pressing the EXECUTE key)

Step 2-1



PRELIMINARY LOGGING ANALYSIS SYSTEM

```
Please choose one of the following eight PLANS programs:
1. SKYMOBILE ....Analyze skyline payloads and spans for individual profiles.
2. SKYTOWER.....Analyze payloads and spans for large central landings.
3. HIGHLEAD .....Analyze direct pull and tightlining limits for highlead.
4. ROUTES .......Project trial grade lines and calculate % sideslopes.
5. SLOPE.........Plot overlay maps for areas of specified slope, aspect, etc.
6. VISUAL ........View a terrain model in perspective from desired viewpoint.
7. SIMYAR ........Simulate yarding activities to estimate yarding cost.
8. MAP ...........Digitize contour lines to create a digital terrain model.

Enter a 1 through 8 to match your choice.
```

Keyboard input: 8

Step 2-2

```
You can now:

1. Create a new DTM unit by digitizing contour lines.
2. Continue digitizing a partially completed DTM unit.
3. Transfer stored DTM unit(s) between the disk and diskettes.
4. Redigitize part of an existing DTM unit.
5. Regrid a DTM unit from a contour-line file.

Enter a 1 through 5 to match your choice.
```

Keyboard input: 2

comment: The partially completed DTM stored in step 1-32 will be completed.

Step 2-3

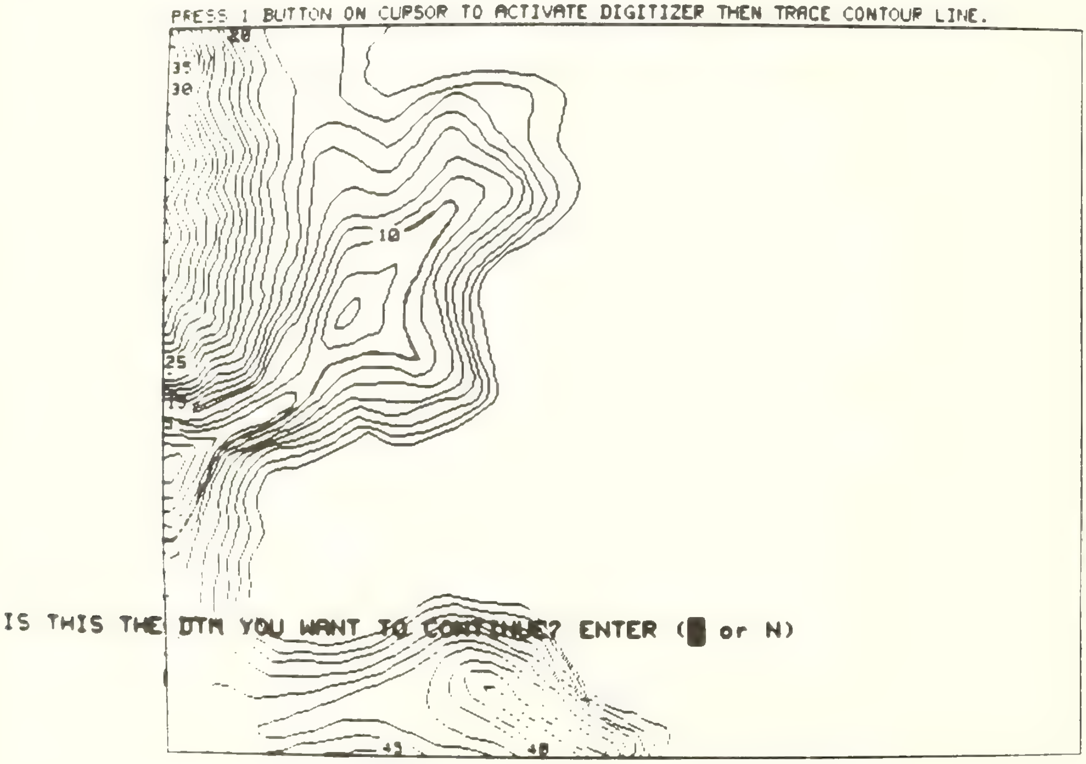
Is the partial DTM unit stored on the HARD DISK or on a DISKETTE?

HARD DISK	DISKETTE	START OVER

Softkey input: HARD DISK

comment: This step provides for loading partial DTM units that had to be stored on 5¼-inch diskettes (see step 1-31).

Step 2-4



```
PRESS 1 BUTTON ON CURSOR TO ACTIVATE DIGITIZER THEN TRACE CONTOUR LINE.
IS THIS THE DTM YOU WANT TO CONTINUE? ENTER (█ or N)
```

IS THIS THE DTM YOU WANT TO CONTINUE? ENTER (Y or N)

Keyboard input: Y

comment: The contour-line pattern should be identical to the pattern printed in step 1-31. If not, input "N" and let program recycle through step 2-3. This gives a chance to recover if the partial DTM was stored on a different 5¼-inch diskette, and the user forgot.

Step 2-5

Attach the DTM unit to the digitizer making sure that its boundary is within the active digitizer surface.

When the unit is attached to the digitizer, press RETURN.

comment: The partial DTM unit will remain stored on the hard disk until it is completed and stored as a gridded DTM unit. At that time, it will be automatically purged from the disk to make the storage space available for a different partial DTM unit. The same holds true for partial DTM units stored on diskettes, providing the diskette is not removed from the internal drive before the DTM is completed.

Only the partial DTM unit that is loaded from the disk can be stored again as an uncompleted partial on disk space. It does not have to be completed during the second contour-line tracing session.

Planners can purge their own partial DTMs from diskettes by typing: PURGE "Cdata1:INTERNAL" (then press the EXECUTE key), and repeating this for Cdata2, Cdata3, Cdata4, and Cdata5.

Step 2-6

Digitize the LOWER LEFT CORNER OF THE DTM UNIT by pressing any cursor key.

Digitizer input:* *1. Center the cursor on the lower left corner of the DTM unit.
2. Press any cursor key.

Step 2-7

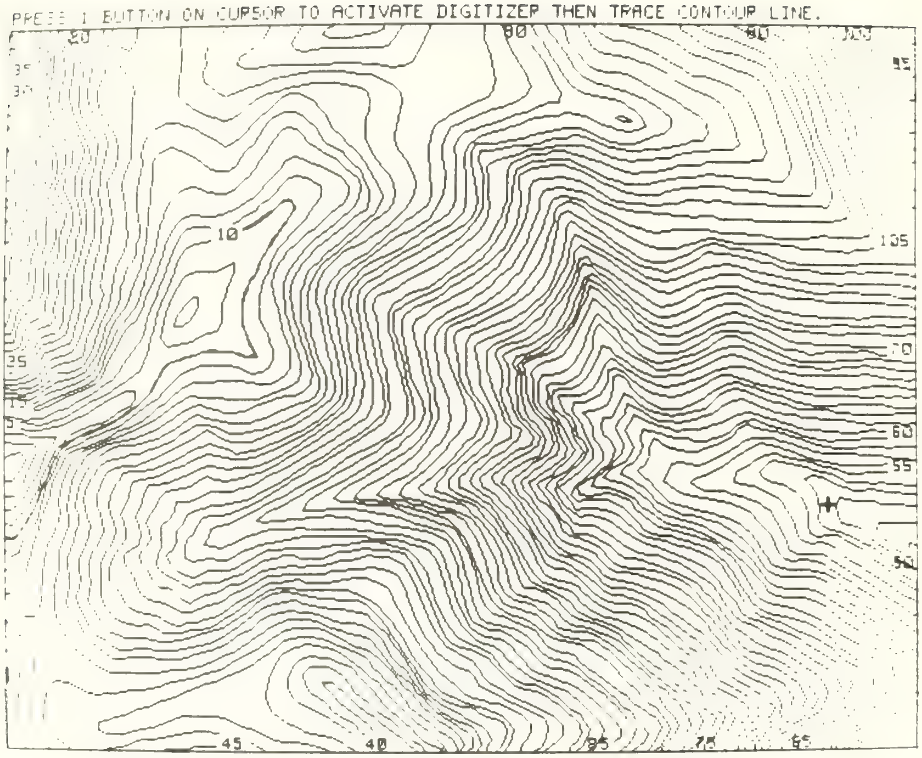
Digitize the LOWER RIGHT CORNER of the DTM unit.

Digitizer input:* *1. Center the cursor on the lower right corner of the DTM unit.
2. Press any cursor key.

Step 2-8

comment: The steps required to complete the DTM unit by digitizing the remaining contour lines are the same as the sequence beginning at step 1-18. The basic operations consist of digitizing the position of the base contour map and the digitizing menu, and digitizing all the remaining contour lines. This procedure was detailed in steps 1-18 through 1-27, and will not be repeated. The procedure (step 2-9) resumes at the point where "Terminate contour line tracing" is activated from the digitizer menu.

Step 2-9



```
PRESS 1 BUTTON ON CURSOR TO ACTIVATE DIGITIZER THEN TRACE CONTOUR LINE.
```

comment: The CRT picture indicates all the contour lines within the DTM unit have been traced.

CRT prompt: The DTM unit you have been digitizing is now:
1. Completed (i.e., all contour lines have been digitized) and will be converted to a gridded digital terrain model now.
2. Partially completed and will be stored on a disk so that further digitizing can be continued later.
3. Partially completed and will be stored for further digitizing and converted to a gridded digital terrain model now.

Enter a 1 through 3 to match your choice.

Keyboard input: 1

comment: Now the DTM unit is complete and ready to be processed into a gridded DTM for PLANS design programs.

Step 2-10

Were contours stored on tape when digitizing of this unit was started? (Y or N)

Keyboard input: Y

comment: The decision was made to store the contour lines in step 1-29; therefore, the additional contour lines should also be stored.

Step 2-11

INSERT A TAPE CARTRIDGE IN THE 7908 DISK DRIVE, THEN PRESS RETURN

comment: The additional contour lines are added to the same data file on the magnetic tape that stored the contour lines of the partial DTM. This data storage may take up to 5 minutes.

Step 2-12

Do you want to add SPOT ELEVATIONS or REFERENCE POINTS to the tape stored contour line file?
(Y or N)

Keyboard input: Y

comment: This option has been included to ensure that the effort made to construct a DTM unit for PLANS can also provide the data base for other DTMs. As there are DTM programs that use spot elevation and reference point data, entering this data might enhance the usefulness of the file. The PLANS DTM processing program (MAP) does not, however, use this data.

The opportunity to enter spot elevation and reference point data is offered only when the DTM unit is completed and ready to be converted to a gridded DTM.

Step 2-13

Use the cursor keys on the digitizer to enter SPOT ELEVATION or REFERENCE POINT DATA.

Center the cursor cross hair on the point you wish to enter.

-If the point is a SPOT ELEVATION: press Cursor key 1
-If the point is a REFERENCE POINT: press Cursor key 2
-When you are done entering points: press Cursor key #

DIGITIZE NOW

Digitizer input: ***1. Center the cursor over the spot elevation point labeled 3391 feet (near the midway point of TEST_DTM1 unit's lower boundary).***
2. Press cursor key 1.

Step 2-14

Enter the elevation in feet from the keyboard.

Keyboard input: 3391

Step 2-15

Use the cursor keys on the digitizer to enter SPOT ELEVATION or REFERENCE POINT DATA.

Center the cursor cross hair on the point you wish to enter.

-If the point is a SPOT ELEVATION: press Cursor key 1
-If the point is a REFERENCE POINT: press Cursor key 2
-When you are done entering points: press Cursor key #

DIGITIZE NOW

Digitizer input: ***1. Center the cursor over the reference point shown as a large "+" in the lower right quadrant of the TEST_DTM1 unit.***
2. Press cursor key 2.

Step 2-16

Enter the REFERENCE POINT description? (80 characters maximum) ->I

Keyboard input:
Point 184,000N and 1,664,000E—Washington State Coordinate (South zone)

comment: The most appropriate reference points for digital terrain model applications tie to State Plane coordinate systems. Recording these points, which establish a specific location for the DTM unit, provides the needed data to make reuse of the DTM more feasible.

Step 2-17

Use the cursor keys on the digitizer to enter SPOT ELEVATION or REFERENCE POINT DATA.

Center the cursor cross hair on the point you wish to enter.

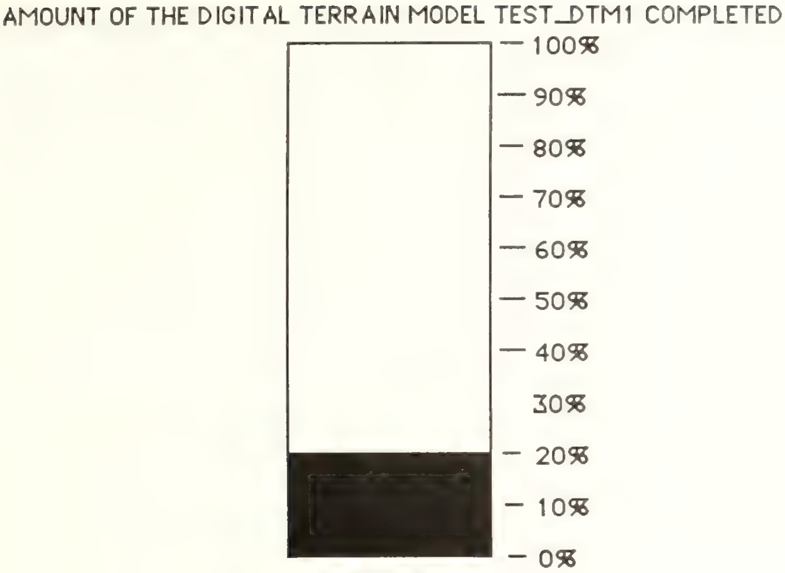
-If the point is a SPOT ELEVATION: press Cursor key 1
-If the point is a REFERENCE POINT: press Cursor key 2
-When you are done entering points: press Cursor key #

DIGITIZE NOW

Digitizer input: ***1. Press cursor key #***

comment: This terminates the example of point-storage operations. A minimum of two reference points are needed, however, to actually establish the location of a DTM coverage area.

Step 2-18



```
AMOUNT OF THE DIGITAL TERRAIN MODEL TEST_DTM1 COMPLETED
```

comment: The program processes the DTM unit into a gridded DTM. This bar chart fills to show progression of processing. This operation takes about 40 seconds to complete.

Step 2-19

SMOOTHING THE DTM

comment: This prompt is displayed until second-stage processing of the DTM unit is completed. Then the PLANS starting menu shown in step 2-1 appears on the CRT.

EXAMPLE 3: COMPLETING ADDITIONAL DTM UNITS AFTER THE FIRST UNIT IS STORED

At this point, the first DTM unit has been completed and stored. The planner now wishes to complete the next DTM unit. Step 1-12 shows that four DTM units comprise the DTM coverage area. The procedure for completing the additional DTMs (that is, TEST__DTM2, TEST__DTM3, and TEST__DTM4) is simpler than that required for TEST__DTM1. The following section details the procedure for building additional DTM units after the first in a group is completed.

The planner accesses the MAP program by typing:
LOAD "PLANS/BEGIN:CS80,5",1 (followed by pressing the EXECUTE key)

Step 3-1

```
PLANS
PRELIMINARY LOGGING ANALYSIS SYSTEM

Please choose one of the following eight PLANS programs:

1. SKYMOBILE ....Analyze skyline payloads and spans for individual profiles.
2. SKYTOWER.....Analyze payloads and spans for large central landings.
3. HIGHLEAD .....Analyze direct pull and tightlining limits for highlead.
4. ROUTES .......Project trial grade lines and calculate % sideslopes.
5. SLOPE.........Plot overlay maps for areas of specified slope, aspect, etc.
6. VISUAL ........View a terrain model in perspective from desired viewpoint.
7. SIMYAR ........Simulate yarding activities to estimate yarding cost.
8. MAP...........Digitize contour lines to create a digital terrain map.

Enter a 1 through 8 to match your choice.
```

Keyboard input: 8

Step 3-2

```
You can now:

1. Create a new DTM unit by digitizing contour lines.
2. Continue digitizing a partially completed DTM unit.
3. Transfer stored DTM unit(s) between the disk and diskettes.
4. Redigitize part of an existing DTM unit.
5. Regrid a DTM unit from a contour-line file.

Enter a 1 through 5 to match your choice.
```

Keyboard input: 1

Step 3-3

Is this DTM unit part of a larger DTM coverage area that contains other previously completed (converted to gridded DTMs) units?
Enter (Y or N).

Keyboard input: Y

comment: TEST_DTM1 has been completed.

Step 3-4

Enter only the character portion of the data files' names for the DTM unit (e.g., enter QUARTZ_CR for data files QUARTZ_CR1, etc.).

Character portion ?

Keyboard input: TEST_DTM

Step 3-5

PRINTER OUTPUT:

The 18.00-inch by 14.00-inch DTM coverage area must be divided into 4 units, 2 horizontally and 2 vertically as shown below.

A data file will be created to store each DTM unit. The name of the data file for storing a DTM unit must be in the following form:

TEST_DTM + the number of the DTM unit (1 to 4).

Note: DTM units must be numbered left to right, bottom to top as shown in the diagram below. It is recommended that this print be saved and used as a record of which map units have been digitized and stored.

TEST_DTM 3	TEST_DTM4
TEST_DTM1	TEST_DTM2

Step 3-6

What is the number of the TEST__DTM DTM unit that you want to digitize ?

***Keyboard input:* 2**

comment: It is best to do the DTM units in ascending numerical order. The boundary to be established prior to digitizing TEST__DTM2 must perfectly match the established boundary of its predecessor, TEST__DTM1. Building the DTM units in order makes accurate fitting of each unit possible.

Step 3-7

comment: From this point on, the procedure is the same as was required for building the first DTM unit (TEST__DTM1). The detailed instructions for this start at step 1-15 (page 16). The documentation there begins with a prompt for digitizing the lower left corner of the unit and proceeds to the point where the DTM unit has been completely digitized and stored. The only difference between digitizing the first unit and additional units is that no input related to sizing the DTM coverage area or establishing the grid spacing is repeated after the first DTM unit has been digitized.

EXAMPLE 4: TRANSFERRING DTM UNITS BETWEEN DISK AND DISKETTE

The planner has completed the DTM units required for the project and an initial timber-harvest plan. Now it is necessary to move the project's DTM unit files from the hard disk to diskettes because memory space on the hard disk is too limiting for it to serve as a permanent storage device for all processed data files. The diskettes that the DTM unit files will be transferred to will be labeled and safeguarded with the project records. When and if additional design on the timber-harvest plan is resumed, the planner will transfer the project's DTM unit files from the diskettes back to the hard disk.

The planner accesses the MAP program by typing:
LOAD "PLANS/BEGIN:CS80,5",1 (followed by pressing the EXECUTE key)

Step 4-1:

```
PLANS
PRELIMINARY LOGGING ANALYSIS SYSTEM

Please choose one of the following eight PLANS programs:

1. SKYMOBILE . . . .Analyze skyline payloads and spans for individual profiles.
2. SKYTOWER. . . . .Analyze payloads and spans for large central landings.
3. HIGHLEAD . . . . .Analyze direct pull and tightlining limits for highlead.
4. ROUTES . . . . . . .Project trial grade lines and calculate % sideslopes.
5. SLOPE . . . . . . . . .Plot overlay maps for areas of specified slope, aspect, etc.
6. VISUAL . . . . . . . .View a terrain model in perspective from desired viewpoint.
7. SIMYAR . . . . . . . .Simulate yarding activities to estimate yarding cost.
8. MAP . . . . . . . . . . .Digitize contour lines to create a digital terrain model.

Enter a 1 through 8 to match your choice.
```

Keyboard input: 8

Step 4-2

You can now:

1. Create a new DTM unit by digitizing contour lines.
2. Continue digitizing a partially completed DTM unit.
3. Transfer stored DTM unit(s) between the disk and diskettes.
4. Redigitize part of an existing DTM unit.
5. Regrid a DTM unit from a contour-line file.

Enter a 1 through 5 to match your choice.

Keyboard input: 3

Step 4-3

These are the DTMs stored in main memory

```
Partial__dtm      1      DIR       42        24 17-Dec-84 10:04 MRW
TEST__DTM1        1 9000 BDAT      101      164 17-Dec-84 13:30 MRW
TEST__DTM2        1 9000 BDAT      101      164 18-Dec-84 09:06 MRW
TEST__DTM3        1 9000 BDAT      101      164 18-Dec-84 14:01 MRW
TEST__DTM4        1 9000 BDAT      101      164 19-Dec-84 09:21 MRW

                  When the diskette is loaded press RETURN
```

comment: The CRT lists the PLANS DTMs that are stored on the disk and requests a diskette be put in the internal drive of the H.P. 9020. If this diskette has not been initialized there will be a 2-minute delay while the program automatically initializes it.

Step 4-4

NO FILES ON DISKETTE

Select option—press soft key:

TRANSFER FILE	WRONG DISKETTE LET ME CHANGE IT		END OF TRANSFER

Softkey input: TRANSFER FILE

Step 4-5

This is what is now stored on the diskette.

Enter the name of the DTM file you want to transfer.

Keyboard input: TEST__DTM1

comment: The file "TEST__DTM1" on the disk is to be copied to the diskette.

Step 4-6

THE FOLLOWING OPTIONS FOR MANIPULATING THE DTM FILE: TEST__DTM1 ARE AVAILABLE:
-Copy from the hard disk to the diskette and PURGE the original hard disk DTM file
-Copy from the hard disk to the diskette and keep both DTM files
-Copy from diskette to the disk and PURGE the original diskette DTM file
-Copy from diskette to the disk and keep both DTM files

Select the transfer option for TEST__DTM1

DISK->DISKETTE	DISK->DISKETTE	DISKETTE->DISK	DISKETTE->DISK
PURGE DISK COPY	KEEP BOTH COPIES	PURGE DISKETTE	KEEP BOTH COPIES

Softkey input: DISK->DISKETTE
KEEP BOTH COPIES

comment: Clearing hard disk space requires that the "purge disk copy" softkey be used. Use the "keep both copies" softkey now because purging the TEST__DTM1 unit from the hard disk will impact ready use by others of the PLANS program user's documentation.

Steps 4-4 through 4-6 will be repeated to allow more DTMs to be copied. When the "end of transfer" softkey is pressed in step 4-4, the program returns to the PLANS starting menu shown in step 4-1.

Note that the options provided in this routine can transfer the project's DTM unit files from the diskettes back to the hard disk. Putting the DTM units back on the hard disk when project design is resumed greatly conveniences DTM operations. It can also be a necessity if all the project's DTM units cannot be stored on a single diskette.

EXAMPLE 5: CORRECTING A DTM BY REDIGITIZING ITS INCORRECT SECTIONS

The planner has finished constructing the TEST__DTM1 DTM unit. Subsequent analysis of the DTM unit via the PLANS SLOPE program discloses that a limited section of the TEST__DTM1 unit has elevation data that does not correspond to the contour map it was traced from (that is, the DTM unit is not correct). Most of the DTM unit is correct, however. The planner wants an entirely correct DTM, but does not want to redigitize any more contour information than is absolutely necessary.

The planner begins the DTM unit's correction by typing:
LOAD "PLANS/BEGIN:CS80,5",1 (followed by pressing the EXECUTE key)

Step 5-1

```
PLANS
PRELIMINARY LOGGING ANALYSIS SYSTEM

Please choose one of the following eight PLANS programs:
1. SKYMOBILE ....Analyze skyline payloads and spans for individual profiles.
2. SKYTOWER.....Analyze payloads and spans for large central landings.
3. HIGHLEAD .....Analyze direct pull and tightlining limits for highlead.
4. ROUTES .......Project trial grade lines and calculate % sideslopes.
5. SLOPE.........Plot overlay maps for areas of specified slope, aspect, etc.
6. VISUAL ........View a terrain model in perspective from desired viewpoint.
7. SIMYAR ........Simulate yarding activities to estimate yarding cost.
8. MAP...........Digitize contour lines to create a digital terrain model.

Enter a 1 through 8 to match your choice.
```

Keyboard input: 8

Step 5-2

```
You can now:

1. Create a new DTM unit by digitizing contour lines.
2. Continue digitizing a partially completed DTM unit.
3. Transfer stored DTM unit(s) between the disk and diskette.
4. Redigitize part of an existing DTM unit.
5. Regrid a DTM unit from a contour-line file.

Enter a 1 through 5 to match your choice.
```

Keyboard input: 4

Step 5-3

Enter the data file name for the desired DTM unit.

Keyboard input: TEST__DTM1

Step 5-4

Attach map to digitizer surface, then press RETURN.

Step 5-5

Digitize the LOWER LEFT corner of the DTM UNIT.

Step 5-6

Digitize the LOWER RIGHT corner of the DTM UNIT.

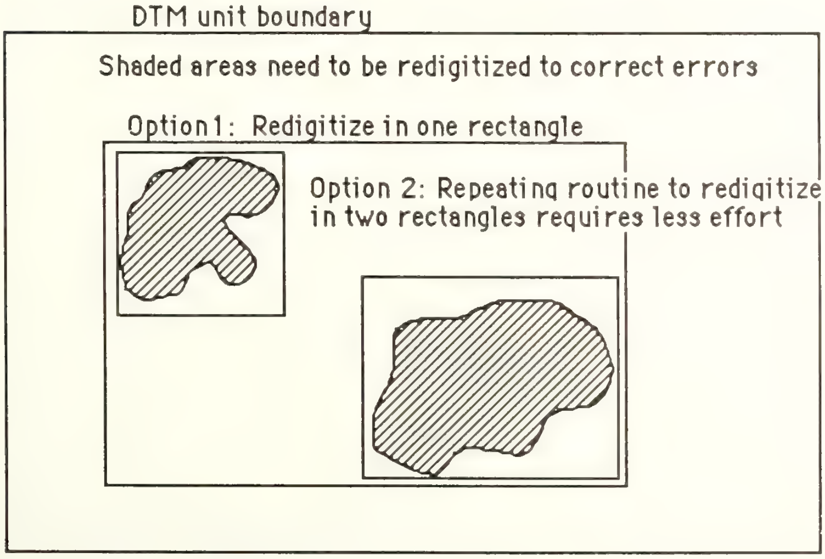
Step 5-7

Mark the area to be redigitized (it must be rectangular), then press RETURN.

comment: The area to be redigitized is essentially a small DTM inside the boundary of the DTM unit. The error in the DTM unit must be contained within the boundaries of the redigitized areas. This error can be caused by inaccurate contour-line digitizing or mislabeling of contour-line elevations.

If there are several areas containing errors within the DTM unit, it may take less digitizing to repeat the process several times with smaller rectangles than to encompass all these areas into one rectangle for redigitizing (see figure below).

Be sure to mark the rectangular boundaries parallel to to the DTM unit's boundaries.


DTM unit boundary
Shaded areas need to be redigitized to correct errors
Option 1: Redigitize in one rectangle
Option 2: Repeating routine to redigitize in two rectangles requires less effort

----

Step 5-8

Digitize the LOWER LEFT corner of the area to be redigitzed.

Step 5-9

Digitize the LOWER RIGHT corner of the area to be redigitzed.

Step 5-10

Digitize the UPPER RIGHT corner of the area to be redigitzed.

comment: This defines the area that will be redigitized. The boundary may shift slightly from the boundary digitized because the new DTM subunit that will be redigitized is fit within the gridline framework of the larger DTM unit.

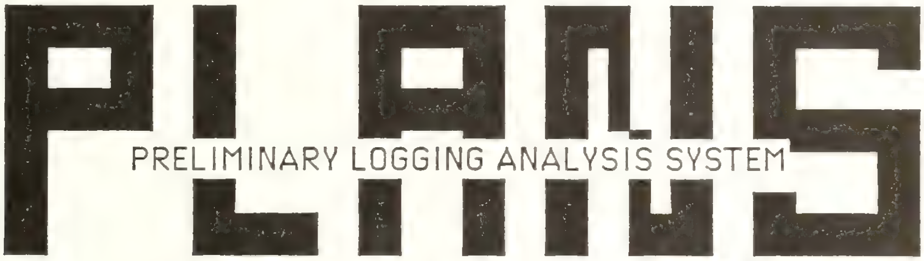
From this point on, the detailed instructions proceed from step 1-18 in the same manner as if a new DTM unit were being built.

EXAMPLE 6: REGRID A DTM UNIT FROM A CONTOUR-LINE FILE

The planner had completed the DTM units required for the project and an initial timber harvest plan. The DTM units for the project were transferred to a diskette and purged from the hard disk. Some revisions are required on the initial harvest plan, but the diskette on which the project's DTM units are stored cannot be found! The planner, however, had stored the contour lines on magnetic tape that were digitized while the DTM units were created. To avoid redigitizing the contour lines to recreate the gridded DTM units needed for the plan revisions, the planner elects to automatically re-create the gridded DTM units needed from the contour-line data stored on the magnetic tape.

The planner begins this recovery process by typing:
LOAD "PLANS/BEGIN:CS80,5",1 (followed by pressing the EXECUTE key)

Step 6-1



```
 Please choose one of the following eight PLANS programs:
1. SKYMOBILE ....Analyze skyline payloads and spans for individual profiles.
2. SKYTOWER.....Analyze payloads and spans for large central landings.
3. HIGHLEAD .....Analyze direct pull and tightlining limits for highlead.
4. ROUTES .......Project trial grade lines and calculate % sideslopes.
5. SLOPE.........Plot overlay maps for areas of specified slope, aspect, etc.
6. VISUAL ........View a terrain model in perspective from desired viewpoint.
7. SIMYAR ........Simulate yarding activities to estimate yarding cost.
8. MAP...........Digitize contour lines to create a digital terrain model.

Enter a 1 through 8 to match your choice.
```

Keyboard input: 8

Step 6-2

```
You can now:

1. Create a new DTM unit by digitizing contour lines.
2. Continue digitizing a partially completed DTM unit.
3. Transfer stored DTM unit(s) between the disk and diskette.
4. Redigitize part of an existing DTM unit.
5. Regrid a DTM unit from a contour-line file.

 Enter a 1 through 5 to match your choice.
```

Keyboard input: 5

comment: The reprocessed DTM unit will have the same size, grid spacing, and elevations as the DTM unit that was processed when the contour lines were stored on the tape.

Step 6-3

TO BUILD A DTM UNIT FROM A CONTOUR-LINE DATA FILE, YOU MUST HAVE STORED THE CONTOUR LINES WHILE DIGITIZING THE CONTOUR MAP. IF CONTOUR LINES WERE NOT STORED, YOU CANNOT RECREATE THE DTM.

What is the name of the contour-line file?

Keyboard input: TEST__DTM1RC

comment: Note that the contour-line files have an RC ending. The routine that stores the raw contour-line data automatically assigns the same file name as the user previously had input in steps 1-12 and 1-14, with an RC ending to differentiate it from the gridded DTM file.

Step 6-4

INSERT A TAPE CARTRIDGE IN THE H.P. 7908 TAPE DRIVE, THEN PRESS RETURN

comment: Wait for the BUSY light to go out before pressing RETURN.

Step 6-5

Enter a name for storing the gridded DTM unit (1 to 14 characters).

Keyboard input: TEST__DTM1

comment: Messages prior to the name request show briefly on the CRT. A catalog of the files on the magnetic tape is shown. If TEST__DTM1RC was not present, the user would be asked to load a different tape or return to the main PLANS menu.

A calculation progress message occupies the screen while the contour data is processed.

The input prompt requests the user enter a name for the gridded DTM. Using the original name relates it to TEST__DTM2, TEST__DTM3, and TEST__DTM4. Related DTM units can be combined to form a larger DTM coverage area for use in PLANS design routines.

Step 6-6

comment: The final steps are identical to steps 2-15 and 2-16. These conclude with the gridded DTM unit being stored on the H.P. 7908P disk in a file named TEST__DTM1.

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~~PNW-201~~

Agriculture

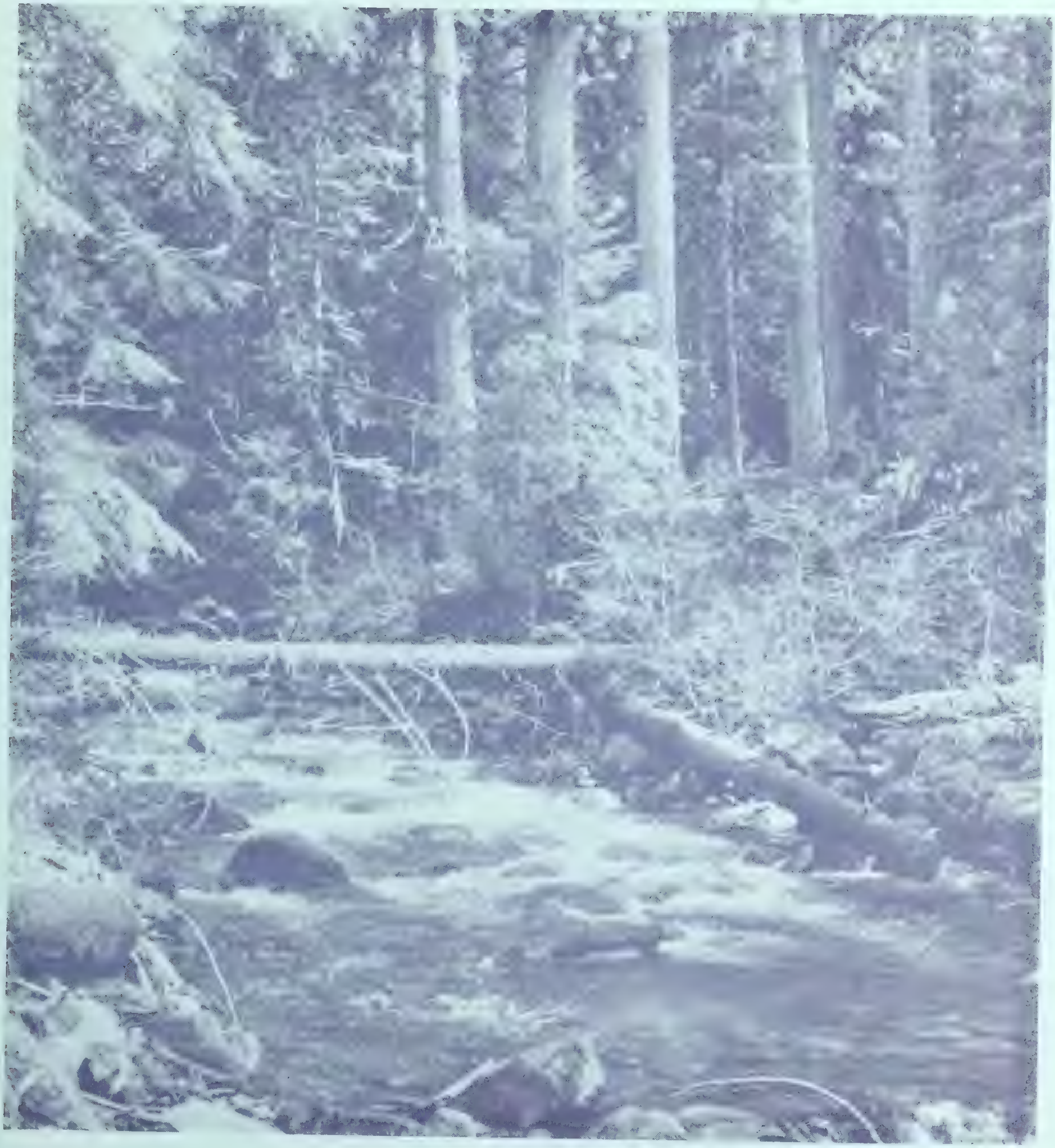
Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-201

April 1987

Research Publications of the H.J. Andrews Experimental Forest, Cascade Range, Oregon, 1948 to 1986



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Research Publications of the H.J. Andrews Experimental Forest, Cascade Range, Oregon, 1948 to 1986

Arthur McKee,
Gary M. Stonedahl,
Jerry F. Franklin, and
Frederick J. Swanson
Compilers

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Abstract

McKee, Arthur; Stonedahl, Gary M.; Franklin, Jerry F.; Swanson, Frederick J., comps. 1987. Research publications of the H.J. Andrews Experimental Forest, Cascade Range, Oregon, 1948 to 1986. Gen. Tech. Rep. PNW-GTR-201. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 74 p.

A list of publications resulting from research at the H.J. Andrews Experimental Forest, Willamette National Forest, Oregon, from 1948 to 1986 is presented. Nearly 600 publications are listed, including papers, theses, and abstracts. An index is provided that cross-references the listings under appropriate keywords.

Keywords: Bibliographies (forestry), Oregon (H.J. Andrews Exp. For.), H.J. Andrews Exp. For.—Oregon.

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Introduction

This bibliography covers the period from establishment of the H.J. Andrews Experimental Forest, in 1948, to 1986, and the publications reflect the evolving of the research program at the Forest. The first research efforts focused on efficiency of logging and road systems and success of forest regeneration. During the 1960's, the emphasis shifted to watershed studies that examined the effects of logging on water yield and quality. Beginning about 1970, the focus shifted to ecosystems, and studies of nutrient cycling, energy flow, and community dynamics were started.

Use of the H.J. Andrews Forest grew rapidly during the 1970's as a result of increased support from the National Science Foundation (NSF) through the International Biological Program and grants for individual projects. Further expansion of ecosystem research has occurred during the 1980's with the NSF-funded Long-Term Ecological Research Program, and research in applied forestry has increased. A balance currently exists between silvicultural and ecosystem studies. Results of research at the H.J. Andrews Forest have been widely reported, as evidenced by the nearly 600 listings in this bibliography.

We have tried to include all relevant literature, so all papers, theses, and published abstracts that have resulted from research at the H.J. Andrews Forest and nearby research natural areas are listed. We have also listed papers that include analyses of data or taxonomic studies of collections from the Forest. Some literature may have been omitted inadvertently. Please bring additional publications to our attention so that the next compilation will be more complete.

The publications are arranged alphabetically by author, by date, and by title. Authors' names are given exactly as they appear on the publication. Thus, a publication with initials for the primary author's first name will be listed before one with the first name spelled out, even if the paper was published at a later date. For example, Hawkins, C.P. (1983) occurs before Hawkins, Charles (1981).

An index is provided after the bibliography. Publications are listed alphabetically by author under appropriate keywords, and most listings are cross-referenced. All publications in the bibliography are listed in the index.

We regret that reprints of listed items cannot be obtained from a central location. Many papers are available from libraries. Others may be obtained from the authors or from the Pacific Northwest Research Station. If copies are not available from any of those sources, single requests can be addressed to the H.J. Andrews Experimental Forest, Forest Science Department, Oregon State University, Corvallis, OR 97331. Because we make photocopies from our files, we ask that this service be used as a last resort.

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Anderson and Cummins 1979; Anderson and others 1984a; Cummins at al. 1982; Dahm 1984; Dahm and others 1981; Naiman and Sedell 1979a, 1979b; Sedell 1972; Sedell and others 1974; Sollins and others 1985; Ward 1984

Detritus processing:
Aho and others 1973; Anderson 1976a, 1976b; Anderson and Cummins 1979; Anderson and others 1978, 1984a; Anderson and Grafius 1975; Anderson and Sedell 1979; Dahm 1984; Dahm and others 1981; Dudley and Anderson 1982; Edmonds 1974, 1975, 1977; Grafius 1977; Grafius and Anderson 1973, 1979, 1980; Maser and Trappe 1984b; McIntire and Colby 1978; Pereira and others 1982; Sedell and Dahm 1984; Sedell and others 1973, 1974, 1975; Sollins and others 1985; Speaker and others 1984; Triska and Buckley 1978; Triska and others 1975, 1982; Ward 1984

Ecological monitoring:
Dyer and Crossley in press; Hinds and others 1981; McKee 1984; McShane and others 1983; Schowalter and others 1986

Ecosystem modeling:
Aho and others 1973; Brown and others 1972a, 1972b; Carroll 1981a; Colby and McIntire 1978; Coniferous 1977; Cushing and others 1980; Dale and others 1984; Daterman and others 1973; Dyer and Crossley in press; Edmonds 1974, 1975, 1977; Franklin 1982a; Graham 1981a, 1981b; Grier and others 1978; Harris 1984a, 1984b; Hemstrom and Adams 1982; Kline and others 1973; Krzak 1980; Massman 1982, 1983; McIntire 1971; McIntire and Colby 1978; McIntire and others 1971, 1975; Means 1982b; Means and others 1981; Meentemeyer 1977; Overton 1975; Overton and others 1973a, 1973b; Overton and White 1978, 1981; Reed and others 1973; Reed and Waring 1974; Rhoades 1983; Running and others 1975; Sedell and others 1973; Shih and others 1973; Sollins and others 1974, 1979, 1982; Strand 1973a, 1973b, 1974; Strand and Grier 1973; Strand and Nagel 1972; Swanson and others 1973, 1982c; Ward and others 1979; Waring 1971, 1973a, 1973b, 1985; Waring and Edmonds 1974; Waring and others 1973; Waring and Running 1976; Warren 1971; Webb and others 1983; Wiens and Nussbaum 1975

Energy budget (see also carbon cycling):
McIntire and Colby 1978; McIntire and others 1971, 1975; Sollins and others 1974; Strand 1974; Waring 1973b; Waring and others 1973

Environmental gradients:
Dyrness and others 1976; Edmonds 1974; Emmingham 1982; Franklin 1979b; Franklin and Dyrness 1973; Gholz and others 1976; Grier and Running 1977; Hawk and others 1982; Waring and others 1978a; Wiens and Nussbaum 1975; Zobel and others 1976

Environmental indexes and variables (see also moisture stress, photosynthesis, temperature, and transpiration):
Dyer and Crossley in press; Emmingham 1982; Emmingham and Waring 1977; Hinds 1984; Waring 1971, 1973a, 1973b; Waring and Edmonds 1974; Waring and others 1973; Waring and Franklin 1979; Waring and Running 1976, 1978; Zobel 1975; Zobel and others 1973b, 1974, 1976

Environmental pollutants (see also fertilizers and pesticides):
Hemstrom and Franklin 1981; Hinds 1984; Moore and others 1974; Norris and others 1983

Erosion:
Anderson and others 1976; Bergstrom 1979; Brown 1973; Cromack and others 1978; Dyrness 1965b, 1966, 1967a, 1967b, 1970, 1975; Edmonds 1974, 1975, 1977; Franklin 1982b; Franklin and Rothacher 1962; Fredriksen 1965a, 1970, 1972a, 1972b; Fredriksen and others 1975; Fredriksen and Harr 1979; Fredriksen and Moore 1972; Harr 1981; Johnson 1978; Johnson and Beschta 1980; Keller and Swanson 1979; Larson 1981; Larson and Sidle 1980; Mersereau and Dyrness 1972; Rice and others 1972; Rothacher 1959; Swanson 1979, 1980, 1981; Swanson and Dyrness 1975; Swanson and others 1973, 1980, 1981, 1982a, 1982b, 1982c; Swanson and Fredriksen 1982; Swanson and Grant 1982; Swanson and James 1973, 1975a, 1975b; Swanson and Sedell 1978; Swanston 1974, 1976, 1978, 1979, 1981; Swanston and others 1980; Swanston and Swanson 1976; Waring 1973a, 1976

Evaporation (see also transpiration):
Gholz 1979, 1982; Massman 1983; Rothacher 1971; Santantonio 1982; Waring and others 1978a; Waring and Franklin 1979; Zobel 1975

Fallen trees (see also windthrows and woody debris):
Christy and Mack 1984; Maser and Trappe 1984a, 1984b; Ogawa 1977; Silvester and others 1982; Stewart 1984; Thomas and others 1979

Fertilizers, Fertilization:
Anderson and others 1976; Cromack and others 1978; Dyrness 1975; Edmonds 1974, 1977; Fredriksen 1972a; Fredriksen and others 1975; Helgerson and others 1984; Johnson and others 1982; Krzak 1980; Miller and others 1976; Rothacher and Franklin 1964; Waring 1983

Field guides:
Berntsen and Rothacher 1959; Franklin and others 1972b; Hemstrom and others 1982; Topic and Hemstrom 1982

Fire:
Burke 1979; Morrison 1984; Swanson 1981

Fish:
Aho 1976; Aho and others 1973; Aho and Hall 1976; Everest and Meehan 1981; Hall and others 1978; Hawkins 1981; Hawkins and others 1983; Meehan and others 1977; Murphy 1979; Murphy and Hall 1981; Naiman and Sedell 1981; Norris and others 1983; Sedell and Luchessa 1982; Triska and others 1982; Wilzbach and Hall 1985; Wustenberg 1954; Wyatt 1959

Fish habitat:
Everest and Meehan 1981; Murphy 1979; Naiman and Sedell 1981; Sedell and others 1973, 1982; Sedell and Luchessa 1982; Swanson and Lienkaemper 1978; Swanson and Sedell 1978; Triska and Cromack 1980; Wilzbach and Hall 1985; Wustenberg 1954; Wyatt 1959

Flood control (see also storms and storm runoff):
Anderson and others 1976; Bergstrom 1979

Foliage endophytes (see also fungi):
Bernstein and Carroll 1977a; Carroll and Carroll 1978; Petrini and Carroll 1981; Petrini and others 1982

Foliage weight:
Smith and others 1981; Waring 1973a; Waring and others 1982

Food chains (see also trophic relations):
Gregory 1983; Norris and others 1983; Strand 1973a, 1974; Strand and Nagel 1972; Waring 1973b; Waring and Edmonds 1974

Forest:

Age (see also forest structure):
Franklin and others 1979, 1982; Franklin and Spies 1984; Franklin and Waring 1980; Means 1982a, 1982b, 1985; Stewart 1984; Thomas and others 1979; Waring 1982; Waring and Franklin 1979

Canopy:
Christy 1986; Dale and others 1984; Denison 1973; Hawkins 1981; Hawkins and others 1982, 1983; Hinds 1984; Long 1982; Massman 1982, 1983; Murphy and others 1981; Rhoades 1978, 1983; Running and others 1986; Schowalter and others 1986; Stewart 1984; Strand 1974; Strand and Nagel 1972; Voegtlin 1982; Waring 1980c, 1983; Waring and Edmonds 1974

Communities (see also plant communities and forest zones):
Emmingham 1982; Franklin 1965a, 1965b; Franklin and Dyrness 1969, 1973; Gholz and others 1984; Sullivan 1978; Warner 1976; Zobel and others 1973a, 1973b, 1974, 1976

Composition:
Franklin and Dyrness 1969, 1973; Franklin and others 1981; Franklin and Spies 1984; Franklin and Waring 1980; Gashwiler 1970b; Grier and Running 1977; Hawk 1973b, 1977, 1979; Hawk and Dyrness 1972; Hawk and others 1978; Hemstrom and Adams 1982; Long 1982; Miles 1983; Stewart 1984, 1986; Swanson and others 1982b; Zobel and others 1976

Dynamics (see also succession):
Dale and others 1984; DeMars 1969; DeMars and others 1970; Edmonds 1977; Emmingham 1977; Franklin 1982a; Gholz 1978, 1979; Hawk 1977; Hawk and others 1982; Hemstrom and Adams 1982; Herman and DeMars 1970; Herman and others 1975, 1978; Long 1982; Means 1982a, 1982b; Miles 1983; Miles and others 1984; Schowalter and others 1986; Sollins and others 1980a; Stewart 1984, 1986; Waring 1971, 1980a, 1980b, 1980c, 1983; Waring and Schlesinger 1985; Zobel 1975

Fragmentation:
Harris 1984a, 1984b; Ruggiero and Carey 1984

Functions:
Franklin and Spies 1984; Harmon and others 1986; Maser and Trappe 1984a; Sollins and others 1985; Swanson and others 1982b; Waring 1980c, 1985; Waring and Edmonds 1974; Waring and Schlesinger 1985

Management (see also watershed management and stream management):
Anderson and others 1976; Bergstrom 1979; Boyce and Wagg 1953; Carow 1959; Cromack and others 1978; Dyrness 1966; Edmonds 1982b; Forest Industries 1962; Franklin 1965a, 1982b; Franklin and others 1981; Franklin and Spies 1984; Fredriksen 1972a; Fredriksen and others 1975; Fredriksen and Harr 1979; Grier and others 1978; Harris 1984a, 1984b; Harris and others 1982; Hemstrom and others 1982; Johnson and others 1982; Krzak 1980; Larson 1981; Larson and Sidle 1980; Maser and others 1978a, 1978b; Maser and Trappe 1984a, 1984b; McKee and others 1982; Means 1982a, 1982b; Miller and others 1976; Rothacher 1965a; Ruggiero and Carey 1984; Ruth and Silen 1950; Silen 1955; Sollins and others 1982; Swanson and Sedell 1978; Swanston and Swanson 1976; Topic and Hemstrom 1982; USDA, Forest Service, 1958; Waring 1973a, 1976, 1980c; Waring and Schlesinger 1985

Pests:
Franklin and Mitchell 1967; Means 1982b; Schowalter and others 1986; Strand 1971, 1972, 1973a

Regeneration (see also silvicultural practices and succession):
Anderson and others 1976; Berntsen 1958; Berntsen and Rothacher 1959; Campbell and Franklin 1981; Christy 1986; Franklin 1961a, 1963, 1965a, 1968a; Franklin and others 1974, 1979; Franklin and Mitchell 1967; Franklin and Rothacher 1962; Means 1982a, 1982b; Miles 1983; Miles and others 1984; Silen 1952, 1956, 1960; Stewart 1984; Sullivan 1976, 1978; The Timberman 1957; Waring 1976

Structure:
Denison 1973; Denison and others 1972; Edmonds 1975, 1982b; Emmingham 1982; Franklin 1982a; Franklin and others 1979, 1981, 1982; Franklin and Spies 1984; Franklin and Waring 1980; Fujimori 1977; Gholz 1979, 1982; Gholz and others 1977; Grier and Cole 1972; Grier and others 1974; Grier and Logan 1977; Grier and Running 1977; Grier and Waring 1974; Hawk 1973b, 1977, 1979; Hawk and others 1978; Herman and others 1975, 1978; Long 1982; Maser and Trappe 1984a, 1984b; Massman 1982; Means 1982a, 1982b; Mitchell 1974; Pike and others 1977; Stewart 1984; Swanson and others 1982b; Thomas and others 1979; Waring 1973a, 1980c, 1982; Waring and Edmonds 1974; Waring and Franklin 1979

Zones (see also vegetation zones):
Dyrness and others 1971, 1976; Edmonds 1974, 1982b; Franklin 1979b; Franklin and Dyrness 1969, 1973; Hemstrom and others 1982; Topic and Hemstrom 1982

Functional groups (see also community structure and stream communities):
Colby and McIntire 1978; Cummins 1980; Cummins and others 1982, 1984; Dudley and Anderson 1982; Edmonds 1974; Hawkins 1981, 1982; Hawkins and others 1982; Hawkins and Sedell 1981; McIntire and Colby 1978; McIntire and others 1975; Meehan and others 1977; Minshall and others 1983; Sedell and others 1975, 1982; Strand 1973a, 1974; Strand and Nagel 1972; Triska and Cromack 1980; Triska and others 1982; Vannote and others 1980

Fungi (see also foliage endophytes, microbial epiphytes, mycorrhizae, and mycophagy):
Bernstein 1974; Bernstein and Carroll 1977a, 1977b; Bernstein and others 1973; Boyce and Wagg 1953; Carroll 1981a, 1981b; Carroll and Carroll 1978; Carroll and others 1980; Christy and others 1982; Cromack and others 1975, 1977a, 1977b; Denison 1971; Fogel 1973, 1975a, 1975b, 1976a, 1976b, 1979; Fogel and others 1973; Fogel and Peck 1975; Fogel and Trappe 1978; Maser and others 1978a, 1978b; Ogawa 1977; Pereira and others 1982; Petrini and Carroll 1981; Petrini and others 1982; Pike 1972b; Rhoades 1972; Sherwood 1973; Sherwood and Carroll 1974; Sollins and others 1981a; Ure and Maser 1982; Wicklow and Carroll 1981

Genecology:
Campbell 1979; Campbell and Franklin 1981

Geology:
Franklin 1965b; Franklin and Dyrness 1969, 1973; Franklin and others 1972b; Gottesfeld and others 1981; Hickman 1968; Hicks 1981; James 1977; Marion 1981; Rothacher and others 1967; Sullivan 1976; Swanson and James 1973, 1975a, 1975b; Swanson and Swanston 1977; Swanston 1978

Geomorphology:
Hicks 1981; Lienkaemper 1976; Marion 1981; Swanson 1979, 1980, 1981; Swanson and others 1980, 1982a, 1982b, 1982c; Swanson and James 1973, 1975a, 1975b; Swanson and Swanston 1977; Swanston 1978; Swanston and others 1980; Vannote and others 1980; Waring 1980c

Glaciation:
Swanson and James 1973, 1975a, 1975b

Groundwater (see also soil moisture and soil water flux):
Brown and others 1972; Harr and Swanson 1980; Mills 1983; Shih and others 1973; Sollins and others 1980b; Sollins and McCorison 1981; Swanson 1979, 1980; Swanson and others 1983; Triska and others 1984

Habitat types (see also plant communities):
Campbell and Franklin 1979, 1981; Franklin and Dyrness 1969, 1971, 1973; Hemstrom and others 1982; Hickman 1968, 1976; Miles 1983; Sullivan 1978; Topic and Hemstrom 1982; Zobel and others 1974, 1976

Hybridization:
Zobel 1973, 1974a, 1974b, 1975

Hydrologic processes:
Anderson and others 1976; Bergstrom 1979; Brown and others 1972a, 1972b; Coniferous 1977; Edmonds 1975, 1977; Fredriksen and Harr 1979; Harr 1976a, 1976b, 1977, 1979, 1981; Harr and Berris 1983; McIntire and Colby 1978; Overton and White 1978, 1981; Ranken 1974; Rothacher 1963; Shih and others 1973; Sollins and others 1974, 1982; Swanson and others 1973, 1980; Waring 1973a, 1973b, 1985

Infiltration capacity (see also soil moisture):
Harr 1979, 1981; Harr and Berris 1983; Harr and Ranken 1973; Harr and Swanson 1980; Johnson 1978; Johnson and Beschta 1980, 1981; Shih and others 1973; Wells and others 1979

Interception (see also precipitation):
Harr 1979; Massman 1983; Rothacher 1963; Shih and others 1973

Invertebrates:

Aquatic:
Aho and others 1973; Anderson 1976a, 1976b, 1978; Anderson and Cummins 1979; Anderson and others 1978, 1982, 1984a, 1984b; Anderson and Grafius 1975; Anderson and Sedell 1979; Anderson and Wallace 1984; Cassis 1984; Cummins 1980; Cummins and others 1982, 1984; Dudley 1982; Dudley and Anderson 1982; Edmonds 1974, 1975, 1977; Grafius 1977; Grafius and Anderson 1973, 1979, 1980; Harper and Wildman 1984; Hawkins 1981, 1982; Hawkins and others 1982, 1983; Hawkins and Sedell 1981; Maser and Trappe 1984b; Murphy and Hall 1981; Pereira and others 1982; Peterson and Courtney 1985; Sedell and others 1975; Stonedahl and Lattin 1982; Wilzbach and Hall 1985

Bioenergetics:
Grafius 1977; Grafius and Anderson 1979; Strand 1973a

Biology:
Aho and others 1973; Anderson 1976a, 1976b, 1978; Anderson and Grafius 1975; Anderson and others 1978; Anderson and Sedell 1979; Anderson and Wallace 1984; Andre and Voegtlin 1981; Cooper 1981; Cummins and others 1982; Dudley 1982; Dudley and Anderson 1982; Grafius 1977; Grafius and Anderson 1979, 1980; Hawkins 1982; Hawkins and others 1982; Mahmoud 1979; Rausch 1975; Razafimahatratra 1978, 1980; Schowalter and others 1986; Schwartz 1981; Stonedahl 1982

Feeding strategies:
Aho and others 1973; Anderson 1976a, 1976b; Anderson and Cummins 1979; Anderson and others 1978; Anderson and Grafius 1975; Anderson and Sedell 1979; Anderson and Wallace 1984; André and Voegtlin 1981; Cooper 1981; Cummins and others 1982; Dudley and Anderson 1982; Fogel 1973, 1975a; Grafius 1977; Grafius and Anderson 1973, 1979, 1980; Hawkins 1982; Hawkins and others 1982; Hawkins and Sedell 1981; Pereira and others 1982; Schowalter and others 1986; Strand 1971, 1972, 1973a

Leaf area (see also forest canopy):
Dale and others 1984; Denison 1973; Denison and others 1972; Gholz 1978, 1979, 1982; Gholz and others 1976, 1977, 1979; Grier and Running 1977; Hawk and others 1978; Hemstrom and Adams 1982; Long 1982; Massman 1982; McNabb and Cromack 1983; Mitchell 1974; Running and others 1975; Smith and others 1981; Sollins and others 1980a; Tucker and Emmingham 1977; Waring 1980a, 1980b, 1983, 1985; Waring and others 1977, 1978a, 1982

Lichens (see also microbial epiphytes):
Carroll 1980, 1981a; Cooper and Carroll 1978; Denison 1973; Horstman and others 1982; Howe 1978; Pike 1972a, 1978, 1981; Pike and others 1972, 1975, 1977; Rhoades 1977, 1978, 1983; Sherwood and Carroll 1974; Ure and Maser 1982; Wicklow and Carroll 1981

Life table analysis:
Mitchell 1974; Rhoades 1983

Lignin content (see also decomposition):
Meentemeyer 1977; Sedell and others 1974; Sollins and others 1981b, 1985; Triska and others 1975; Triska and Sedell 1976

Parasitic:
Lewis and Maser 1981; Rausch 1975

Soil:
Cromack and others 1977a, 1977b; Krantz and others 1973; McBrayer and others 1977; Strand 1973a

Terrestrial:
André 1980; André and Voegtlin 1981; Carroll 1980, 1981a; Cooper 1981; Daterman and others 1973; Emerson and others 1984; Fogel 1973, 1975a; Fogel and Peck 1975; Gashwiler and Ward 1968; Henry and Lattin in press a, in press b; Krantz and others 1973; Lattin in press; Lattin and Oman 1983; Lewis and Maser 1981; Lightfoot 1986; Mahmoud 1979; Maser and Trappe 1984b; Mispagel and Rose 1978; Phillips 1983; Razafimahatratra 1978, 1980; Schwartz 1981; Stonedahl 1982, 1984; Stonedahl and Lattin 1986; Strand 1971, 1972, 1973a, 1974; Voegtlin 1982; Whitaker and others 1977; Whitaker and Maser 1976, 1984

Litter, Litterfall:

Aquatic (see also organic matter [streams] and stream detritus):
Cummins and others 1983; Grafius and Anderson 1979; Sedell and others 1974, 1975, 1982; Triska and Buckley 1978; Triska and Cromack 1980; Triska and others 1975, 1982, 1984; Triska and Sedell 1976; Warner 1976

Terrestrial:
Abee and Lavender 1972; Carroll 1981a; Denison 1971; Fogel and Cromack 1974, 1977; Fogel and others 1973; Gilmour and others 1973; Graustein and others 1977; Grier and Cole 1972; Grier and others 1974; Grier and Logan 1977; Harris and others 1980; Hinds 1984; Hinds and others 1981; Howe 1978; Johnson and others 1982; Long 1982; McBrayer and others 1977; McShane and others 1983; Meentemeyer 1977; Mersereau and Dyrness 1972; Miller and others 1976; Ogawa 1977; Philips 1975; Pike 1978; Rhoades 1978; Santantonio 1982; Schoenberger and Perry 1982; Sollins and others 1980b; Strand 1973b; Strand and Grier 1973; Swanson and others 1980, 1982a; Triska and Cromack 1980; Warner 1976; Wells and others 1979

Mammals:
Black 1971; Black and Taber 1977; Dealy 1959, 1966; Doyle 1985; Emerson and others 1984; Fogel and Trappe 1978; Franklin and others 1972b; Gashwiler 1959, 1963, 1965a, 1965b, 1967, 1970a, 1970b, 1971a, 1977, 1979; Harris and others 1982; Lewis and Maser 1981; Maser and others 1978a, 1978b; McCullough 1964; Nussbaum and Maser 1975; Rausch 1975; Ure and Maser 1982; Whitaker and others 1977; Whitaker and Maser 1976, 1984

Mass movement (see also debris torrents, erosion, and soil movement):
Dyrness 1967b; Everest and Meehan 1981; Fredriksen 1963, 1965b, 1970; Fredriksen and Harr 1979; Harr 1981; Harr and Swanson 1980; Hicks 1981; Marion 1981; Miles 1983; Miles and others 1984; Mills 1983; Paeth 1970; Paeth and others 1971; Rice and others 1972; Rothacher 1965a; Simons and others 1978; Swanson and Dyrness 1975; Swanson and others 1973, 1976a, 1976b, 1980, 1981, 1982a, 1982c, 1983, 1985; Swanson and Fredriksen 1982; Swanson and James 1973, 1975a, 1975b; Swanson and Lienkaemper 1978, 1985; Swanson and Sedell 1978; Swanson and Swanston 1977; Swanston 1974, 1976, 1978, 1979, 1981; Swanston and others 1980; Swanston and Swanson 1976; Ward and others 1978, 1979

Meteorology (see also precipitation, solar radiation, and temperature):
Berntsen and Rothacher 1959; Coniferous 1977; Edmonds 1974, 1975, 1977, 1982b; Emmingham 1982; Emmingham and Lundberg 1977; Franklin 1965b; Franklin and Dyrness 1969, 1973; Franklin and others 1972b; Franklin and Waring 1980; Grier and Cole 1972; Grier and Running 1977; Harr 1981; Harr and Berris 1983; Harr and others 1982; Hawk 1977; Kline and others 1973; Massman 1983; McCullough 1964; Meentemeyer 1977; Minshall and others 1983; Reed and Waring 1974; Rothacher and others 1967; Running 1976; Sollins and others 1974, 1979; Sullivan 1976; Swift and Ragsdale 1985; Waring 1982; Waring and others 1978b; Waring and Franklin 1979; Webb and others 1983

Microbial epiphytes (see also lichens, mosses, and fungi):
Bernstein 1974; Bernstein and Carroll 1977b; Bernstein and others 1973; Carroll 1973, 1979, 1980, 1981a; Denison 1971, 1973; Pike 1978; Pike and others 1972, 1975, 1977; Swisher and Carroll 1980; Waring 1980c

Moisture stress (see also water balance, water flux, and water relations):
Dyrness 1973a; Edmonds 1974, 1975; Emmingham 1982; Emmingham and Lundberg 1977; Emmingham and Waring 1977; Gholz and others 1976; Hawk and others 1978, 1982; Hawk and Zobel 1974; Hemstrom and Adams 1982; Hichman 1968; McNabb and Cromack 1983; Reed and Waring 1974; Running 1976; Santantonio 1982; Sollins and others 1981b; Tucker and Emmingham 1977; Waring 1971, 1973a, 1973b, 1980a, 1980b, 1983, 1985; Waring and others 1973, 1978a; Waring and Franklin 1979; Waring and Running 1976, 1978; Webb and others 1978, 1983; Zobel 1971, 1974a, 1975; Zobel and others 1973a, 1974, 1976

Mosses:
Binkley and Graham 1981; Carroll 1980; Naiman and Sedell 1980; Pike and others 1972, 1975, 1977; Triska and others 1984

Mycophagy:
André and Voegtlin 1981; Fogel 1973, 1975a; Fogel and Peck 1975; Fogel and Trappe 1978; Maser and others 1978a, 1978b; Ure and Maser 1982

Mycorrhizae:
Christy and others 1982; Maser and others 1978a, 1978b; Maser and Trappe 1984a, 1984b; Schoenberger and Perry 1982; Trappe and Fogel 1977; Triska and Cromack 1980

Needle morphology:
Tucker and Emmingham 1977; Zobel 1973

Nitrogen:

Dynamics (see also nigrogen fixation and nutrient cycling):
Abee and Lavender 1972; Aumen and others 1983, 1985a, 1985b; Binkley 1984a, 1984b; Binkley and others 1982; Buckley and Triska 1978; Carroll 1980; Cole and Rapp 1980; Cromack and others 1978; Denison 1973; Edmonds 1977; Fredriksen 1971, 1972b, 1975; Grier and Cole 1972; Helgerson 1981; Helgerson and others 1984; Henderson and others 1978; Johnson and others 1982; Krzak 1980; McNabb and Cromack 1983; Pike 1978; Pike and others 1972; Smith and others 1981; Sollins and others 1977, 1980b, 1981a, 1984, 1985; Sollins and McCorison 1981; Spycher and others 1983; Triska and Buckley 1978; Triska and Cromack 1980; Triska and others 1975, 1982, 1984; Triska and Sedell 1976; Ward 1984, 1985; Waring 1980b; Wells and others 1979

Fixation:
Binkley 1984b; Buckley and Triska 1978; Helgerson 1981; Helgerson and others 1984; Horstman and others 1982; Howe 1978; Johnson and others 1982; McNabb and Cromack 1983; Pike 1978; Silvester and others 1982; Sollins and others 1980b; Triska and others 1984; Ward 1984

Nutrient(s):

Budgets (see also nutrient cycling):
Binkley 1984a, 1984b; Fredriksen 1972b, 1975; Fredriksen and Moore 1972; Gholz and others 1984; Grier and others 1974; Henderson and others 1978; Johnson and others 1982; Krzak 1980; Sedell and Dahm 1984; Sollins and others 1974, 1980b; Sollins and McCorison 1981; Triska and others 1984

Cycling:
Abee 1973; Abee and Lavender 1972; Bergstrom 1979; Binkley 1984a, 1984b; Binkley and others 1982; Binkley and Graham 1981; Carroll 1980; Carroll and others 1980; Cole and Rapp 1980; Cromack and others 1975, 1977a, 1977b, 1978; Cummins 1980; Edmonds 1974, 1975, 1977; Franklin 1982b; Franklin and others 1981; Fredriksen 1971, 1972b, 1975; Fredriksen and Harr 1979; Fredriksen and Moore 1972; Graustein and others 1977; Grier and Cole 1972; Grier and others 1974, 1978; Harris and others 1980; Hawk and others 1978; Henderson and others 1978; Johnson and others 1982; Krzak 1980; Lavender 1971; Maser and Trappe 1984a, 1984b; Miller and others 1976; Minshall and others 1983; Norris and others 1983; Pike 1978; Santantonio 1981, 1982; Silvester and others 1982; Sollins and others 1974, 1977, 1980b, 1981a, 1981b, 1982; Sollins and McCorison 1981; Strand 1973b; Strand and Grier 1973; Triska and others 1982, 1984; Waring 1973b, 1980c; Waring and Edmonds 1974; Waring and Franklin 1979; Wells and others 1979

Leaching (see also nutrient cycling):
Carroll 1980; Cooper and Carroll 1978; Edmonds 1975, 1977; Grier and Cole 1972; Harris and others 1980; Johnson and others 1982; Miller and others 1976; Pike 1978; Schoenberger and Perry 1982; Sollins and others 1980b; Sollins and McCorison 1981; Strand and Grier 1973; Triska and Buckley 1978; Triska and others 1975, 1984

Litter:
Fogel and Cromack 1974; Grier and others 1974; Hinds 1984; Miller and others 1976; Sollins and others 1980b, 1985; Triska and Cromack 1980; Triska and others 1975, 1984; Triska and Sedell 1976

Microbial epiphytes:
Carroll 1980; Fogel 1976a; Pike 1978; Pike and others 1972

Roots:
Miller and others 1976; Santantonio and others 1977

Soil:
Brown 1973; Brown and Parsons 1973a, 1973b; Cole and Rapp 1980; Cromack and others 1978; Edmonds 1975, 1977; Fredriksen and Moore 1972; Graustein and others 1977; Grier and Cole 1972; Grier and others 1974; Harris and others 1980; Johnson and others 1982; Krzak 1980; Miller and others 1976; Paeth and others 1971; Schoenberger and Perry 1982; Sollins and others 1980b, 1981b, 1983, 1984, 1985; Sollins and McCorison 1981; Spycher and others 1983; Swanson 1980; Swanson and others 1982a; Tarrant 1956b; Warner 1976

Stream:
Aho and others 1973; Cummins 1980; Edmonds 1975; Fredriksen 1971, 1972a, 1972b, 1975; Fredriksen and others 1975; Fredriksen and Harr 1979; Gregory 1976, 1978; Henderson and others 1978; Maser and Trappe 1984b; Miller and others 1976; Minshall and others 1983; Moeller and others 1979; Naiman and Sedell 1979a, 1979b, 1981; Rothacher and others 1967; Sedell and others 1973; Sollins and others 1980b; Sollins and McCorison 1981; Swanson and others 1982a; Ward 1984, 1985

Vascular plants:
Carroll 1980; Fogel and others 1973; Gholz 1978; Grier and Cole 1972; Grier and others 1974; Johnson and others 1982; Krzak 1980; Miller and others 1976; Overton and others 1973a; Smith and others 1981; Sollins and others 1980b; Waring 1980b; Zobel and others 1974, 1976

Old-growth forests:
Cline and Phillips 1983; Forsman and others 1984; Franklin 1982b; Franklin and others 1979, 1981; Franklin and Spies 1984; Gholz and others 1976; Gratkowski 1956; Grier and Logan 1977; Harris 1984a, 1984b; Harris and others 1982; Herman and DeMars 1970; Herman and others 1975; Hermann 1973; Howe 1978; Levno and Rothacher 1967; Maser and Trappe 1984a, 1984b; Massman 1982; Overton and others 1973a; Pike and others 1972, 1975, 1977; Rhoades 1978, 1983; Rothacher 1963; Ruggiero and Carey 1984; Santantonio 1974; Santantonio and others 1977; Schoenberger and Perry 1982; Sherwood and Carroll 1974; Sollins and others 1980b, 1981b; The Timberman 1957; Voegtlin 1982; Waring 1982; Waring and Running 1978; Yerks 1958

Organic matter:

Budgets:
Cummins and others 1983; Edmonds 1974; Moeller and others 1979; Sedell and others 1973, 1974; Sollins and others 1980b; Swanson and others 1982a; Triska and others 1982; Waring and Edmonds 1974

Distribution:
Grier and others 1974; Grier and Logan 1977; Johnson and others 1982

Soil:
Harris and others 1980; Santantonio 1982; Sollins and others 1984; Spycher and others 1983; Strand 1973b; Strand and Grier 1973; Wells and others 1979

Streams (see also litter and litterfall [aquatic], stream detritus, and woody debris [streams]):
Cummins and others 1983; Dahm and others 1981; Minshall and others 1983; Murphy and others 1981; Naiman and Sedell 1979a, 1979b, 1980, 1981; Sedell and others 1973, 1974, 1978, 1982; Sollins and others 1985; Swanson 1979; Swanson and others 1980, 1982a, 1982b; Triska and Cromack 1980; Triska and others 1982, 1984; Vannote and others 1980; Waring and Edmonds 1974

Organization:
McKee 1984

Paleobotany:
Gottesfeld and others 1981; Waring and Franklin 1979

Periderm color:
Zobel 1973, 1974b

Periphyton (see also algae):
Aho and others 1973; Cummins 1980; Edmonds 1977; Lyford and Gregory 1975; McIntire 1971; McIntire and Colby 1978; Murphy and Hall 1981; Naiman and Sedell 1980, 1981; Pereira and others 1982; Rounick and Gregory 1981; Sedell and others 1973; Triska and others 1982

Pesticides:
Anderson and others 1976; Fredriksen and others 1975; Moore and others 1974; Sollins and others 1981b

Phenology:
Campbell and Franklin 1979; Dyrness 1973a; Emmingham 1977; Fogel 1976a; Gholz 1978; Hickman 1968; McKee 1972; McKee and others 1981; Rounick and Gregory 1981; Russel 1974; Waring and Edmonds 1974; Zobel and others 1974

Phenophases:
McKee 1972; Zobel and others 1974

Photoperiod (see also solar radiation):
McCullough 1964; McKee and others 1981

Photosynthesis:
Edmonds 1975; Emmingham 1982; Emmingham and Waring 1977; Naiman and Sedell 1980; Reed and others 1973; Waring 1980b; Waring and others 1973, 1978a; Waring and Franklin 1979; Waring and Running 1978; Webb and others 1983; Zobel 1974a

Plant communities:
Campbell and Franklin 1979, 1981; Dyrness 1965a, 1973b; Dyrness and others 1971, 1976; Dyrness and Hawk 1972; Edmonds 1974, 1977; Emmingham 1982; Emmingham and Lundberg 1977; Franklin 1965a, 1965b, 1979b; Franklin and Dyrness 1969, 1971, 1973; Franklin and others 1972b; Gholz and others 1976; Grier and Logan 1977; Hawk 1973b, 1977, 1979; Hawk and Dyrness 1972; Hawk and others 1978, 1982; Hawk and Zobel 1974; Hemstrom and others 1982; Hickman 1968, 1976; McKee and others 1981; Miles 1983; Rothacher and others 1967; Sullivan 1976, 1978; Topic and Hemstrom 1982; Waring 1973b; Waring and Edmonds 1974; Warner 1976; Zobel and others 1973a, 1973b, 1974, 1976

Plant cover (see also forest composition):
Gashwiler 1970b; Grier and Logan 1977; Hawk 1973b; Hawk and Dyrness 1972; Hawk and others 1978, 1982; Hawk and Zobel 1974; Mersereau and Dyrness 1972; Miles 1983; Sullivan 1978; Wiens and Nussbaum 1975

Population dynamics (see also forest dynamics):

Invertebrates:
Grafius and Anderson 1979, 1980; Hawkins 1982; Schowalter and others 1986; Strand 1973a; Waring 1973a

Lichens:
Rhoades 1977, 1978, 1983

Stream communities:
Grafius and Anderson 1979, 1980; Hawkins 1982; Lyford and Gregory 1975; McIntire 1971; McIntire and Colby 1978; McIntire and others 1975; Murphy 1979

Vertebrates:
Nussbaum and Clothier 1973; Peacock and Nussbaum 1973

Precipitation:
Anderson and others 1976; Christner 1981; Coniferous 1977; Fredriksen 1965a, 1965b, 1970, 1972b, 1975; Gholz 1979, 1982; Grier and Cole 1972; Harr 1976b, 1977, 1979, 1981; Harr and Berris 1983; Harr and others 1982; Harr and McCorison 1979; Harr and Ranken 1973; Harr and Swanson 1980; Hawk and others 1982; Henderson and others 1978; Johnson 1978; Long 1982; Massman 1983; McNabb and Cromack 1983; Mispagel and Rose 1978; Rothacher 1959, 1963, 1965a, 1965b, 1970, 1971, 1973; Rothacher and others 1967; Running 1976; Sollins and others 1977, 1979, 1980b; Sollins and McCorison 1981; Swanson 1979; Swanson and others 1973, 1980, 1983; Swanson and Swanston 1977; Swanston 1974, 1981; Swanston and others 1980; Swanston and Swanson 1976; Waring and others 1978b; Waring and Franklin 1979; Waring and Running 1976

Production, Productivity:

Fish:
Aho and Hall 1976; Everest and Meehan 1981; Hawkins 1981

Forests:
Bergstrom 1979; Edmonds 1975, 1977, 1982b; Emmingham 1982; Emmingham and Waring 1977; Franklin 1962, 1964b, 1982b; Franklin and others 1981; Franklin and Spies 1984; Franklin and Waring 1980; Fujimori and others 1976; Gholz 1979, 1982; Gholz and others 1984; Grier and others 1978; Grier and Logan 1977; Krzak 1980; Long 1982; Maser and Trappe 1984b; Miles 1983; Miles and others 1984; Mitchell 1974; Silen and Gratkowski 1953; Sollins and others 1982; Waring 1973a, 1973b, 1980a, 1980b, 1980c, 1983; Waring and Franklin 1979; Webb and others 1978, 1983; Zobel 1971

Microbial epiphytes:
Bernstein and Carroll 1977b; Binkley and Graham 1981; Fogel 1976a; Pike 1978, 1981; Rhoades 1978, 1983; Wicklow and Carroll 1981

Roots:
Harris and others 1980; Santantonio 1981, 1982; Schoenberger and Perry 1982

Streams:
Aho and others 1973; Cummins and others 1983; Edmonds 1974, 1975; Grafius and Anderson 1980; Gregory 1976, 1978a, 1978b, 1980; Lyford and Gregory 1975; McIntire 1971; McIntire and Colby 1978; McIntire and others 1971, 1975; Minshall and others 1983; Moeller and others 1979; Murphy 1979; Murphy and others 1981; Murphy and Hall 1981; Naiman and Sedell 1980, 1981; Sedell and others 1973; Triska and others 1982; Vannote and others 1980

Reference stands:
Brown and Parsons 1973a, 1973b; Dyrness 1973a; Emmingham and Lundberg 1977; Franklin and others 1982; Hawk 1973b; Hawk and others 1978, 1982; Howe 1978; McKee 1972; Zobel and others 1973a, 1973b, 1976

Remote sensing:
Dyer and Crossley in press; Running and others 1986; Sader 1984

Research natural areas (see also biosphere reserves):
Franklin and others 1972b, 1977; Klopsch and others 1979; McKee and others 1977, 1978, 1982

Respiration:
Cummins and others 1983; Edmonds 1975; Grafius and Anderson 1979, 1980; Graham 1981a, 1981b; Gregory 1976; McIntire and Colby 1978; Minshall and others 1983; Murphy and others 1981; Naiman and Sedell 1979a, 1979b, 1980; Philips 1975; Sedell and others 1973; Strand and Grier 1973; Triska and others 1975, 1982; Triska and Sedell 1976; Waring and others 1978a

Riparian vegetation:
Campbell and Franklin 1979; Cummins 1980; Hawk 1973a; Hawkins 1981; Hawkins and others 1982, 1983; Meehan and others 1977; Minshall and others 1983; Sedell and others 1982; Sedell and Froggatt 1984; Sedell and Swanson 1984; Sollins and others 1985; Steinblums and others 1984; Swanson and others 1982b

River continuum:
Cummins 1980; Cummins and others 1983, 1984; Hawkins and Sedell 1981; Minshall and others 1983; Naiman and Sedell 1981; Sedell and others 1982; Vannote and others 1980

Road development:
Berntsen and Rothacher 1959; Dyrness 1966, 1967a, 1970, 1975; Fredriksen 1963, 1965b, 1970; Fredriksen and others 1975; Harr 1976a, 1976b, 1979; Larson 1981; Marion 1981; Rice and others 1972; Ruth and Silen 1950; Silen 1955; Silen and Gratkowski 1953; Swanson and Dyrness 1975; Swanson and others 1981; Swanston 1974, 1976; Swanston and Swanson 1976; The Timberman 1957; Waring 1976

Root:

Dynamics (see also biomass [roots], nutrients [roots], and production [roots]:
Antos and Zobel 1984; Christy 1986; Harris and others 1980; Santantonio 1981, 1982; Santantonio and others 1977; Santantonio and Hermann 1985; Waring 1980c

Zone:
Running and others 1975; Santantonio and Hermann 1985; Waring 1980c; Waring and others 1973; Waring and Running 1976

Sampling methodology and equipment:
Adamus 1984; Addor 1972; Daterman and others 1973; Dealy 1966; Denison and others 1972; Fredriksen 1969; Harr 1973; Harr and Grier 1976; Holbo 1973; Holbo and others 1975; Johnson and Hixon 1952; McShane and others 1983; Means 1985; Mispagel and Rose 1978; Overton and others 1973a; Silen 1956; Swisher and Carroll 1980; Voegtlin 1982

Sapwood cross-sectional area:
Running and others 1975; Waring 1973a, 1980a, 1980b, 1983, 1985; Waring and others 1977, 1982

Sapwood water storage (see also water relations [plants]):
Running and others 1975; Waring 1985; Waring and others 1973; Waring and Running 1976, 1978

Sediment:

Budgets:
Swanson and others 1982a, 1982c; Swanson and Fredriksen 1982

Storage (see also sediments-sedimentation):
Swanson 1980; Swanson and others 1982a, 1982c; Swanson and Fredriksen 1982

Yield (see also sediments-sedimentation):
Larson 1981; Larson and Sidle 1980; Swanson 1979, 1981; Swanson and others 1982a, 1982c; Swanson and Fredriksen 1982

Sediments, Sedimentation (see also alluvial deposits and stream substrates):
Anderson and others 1976; Fredriksen 1965a, 1965b, 1969, 1970, 1972a, 1975; Fredriksen and others 1975; Fredriksen and Harr 1979; Hawk and Zobel 1974; Hawkins 1981; Hawkins and others 1983; Johnson 1978; Meehan and others 1977; Murphy and others 1981; Murphy and Hall 1981; Rice and others 1972; Rothacher 1965a; Rothacher and others 1967; Swanson 1979, 1980, 1981; Swanson and others 1973, 1976, 1980, 1982a, 1982b, 1982c; Swanson and Fredriksen 1982; Swanson and James 1973, 1975a, 1975b; Swanson and Lienkaemper 1978; Swanson and Sedell 1978; Swanson and Swanston 1977; Swanston 1978; Swanston and others 1980; Swanston and Swanson 1976; The Timberman 1957

Seed:

Dispersal:
Carkin and others 1978; Gashwiler 1969

Germination:
Franklin and Krueger 1968; Tarrant 1956b; Tarrant and Wright 1955

Production:
Christy and Mack 1984; Franklin 1968a; Franklin and others 1974; Gashwiler 1965b, 1969, 1971a, 1979; Silen 1952

Source:
Franklin and others 1979; Franklin and Greathouse 1969a, 1969b

Survival:
Christy and Mack 1984; Gashwiler 1965b, 1967, 1970a; Gashwiler and Ward 1966, 1968; Silen 1952

Weight:
Franklin 1968b; Franklin and Greathouse 1969a, 1969b

Seed trees:
Franklin 1963, 1968a

Seed zones:
Campbell and Franklin 1981

Seedling growth and survival (see also forest regeneration):
Berntsen 1958; Christy and others 1982; Christy and Mack 1984; Franklin 1961b, 1962; Franklin and others 1974; Franklin and Rothacher 1962; Gashwiler 1971b; Gashwiler and Ward 1968; Miles 1983; Miles and others 1984; Rothacher and Franklin 1964; Schoenberger and Perry 1982; Silen 1956, 1960; Stewart 1984; Sullivan 1976, 1978; Tarrant 1956b; Tarrant and Wright 1955; Waring 1980b; Zobel 1975; Zobel and others 1973b

Shade or shading:
Aho 1976; Aho and Hall 1976; Christy 1986; Franklin 1961a, 1963, 1964b; Gholz 1978; Hawkins 1981; Hawkins and others 1982, 1983; Levno and Rothacher 1967; Lyford and Gregory 1975; Meehan and others 1977; Murphy and others 1981; Naiman and Sedell 1980; Sedell and Froggatt 1984; Steinblums and others 1984; Stewart 1984; Tucker and Emmingham 1977; Waring 1983

Silviculture (see also forest regeneration, slash or broadcast burning, and timber harvesting):
Committee of Scientists 1977; Franklin 1965a, 1968a; Larson 1981; McKee in press; Means 1982a; Miller and others 1976; Norris and others 1983; Sollins and others 1974, 1982; Sullivan 1976, 1978; Swanston and others 1980

Site classification (see also habitat types):
Dyrness 1973a; Edmonds 1982b; Emmingham 1982; Franklin 1977b, 1980; Franklin and others 1970; Means 1982a

Site index:
DeMars 1969; DeMars and others 1970; Herman and others 1975, 1978; Means and Helm 1985

Slash or broadcast burning:
Anderson and others 1976; Dale and others 1984; Dyrness 1965a, 1966, 1973b; Edmonds 1974; Franklin 1982a; Fredriksen 1970, 1971, 1972a; Gashwiler 1959; Hawk and Zobel 1974; Johnson and others 1982; Krzak 1980; Levno and Rothacher 1969; Means 1982a, 1982b; Mersereau and Dyrness 1972; Rice and others 1972; Rothacher 1971; Schoenberger and Perry 1982; Silen 1952; Stewart 1984; Swanson 1981; Tarrant 1954, 1956a, 1956b; Tarrant and Wright 1955; Waring 1976; Wells and others 1979; Yerkes 1960

Snowmelt:
Anderson and others 1976; Christner 1981; Christner and Harr 1982; Fredriksen 1965a; Harr 1979, 1981; Harr and Berris 1983; Harr and others 1982; Harr and McCorison 1979; Harr and Ranken 1973; Overton and White 1978; Shih and others 1973

Soil:

Disturbance (see also erosion, mass movement, and soil movement):
Cromack and others 1978; Dyrness 1965b, 1966, 1967a, 1967c; Fredriksen 1970; Harr 1976a, 1976b, 1979; Harr and McCorison 1979; Johnson 1978; Johnson and Beschta 1980; Miles 1983; Miles and others 1984; Rice and others 1972; Schoenberger and Perry 1982; Swanson and others 1976a; Swanston 1974, 1981; Tarrant 1956b

Genesis:
James 1977

Mapping:
Dyrness and Hawk 1972; Hawk and Dyrness 1972; Simons and others 1978

Moisture:
Anderson and others 1976; Christner 1981; Dyrness 1969; Edmonds 1975, 1977; Fogel and others 1973; Fredriksen 1970; Harr 1973, 1976b, 1977, 1981; Harr and Berris 1983; Harr and Grier 1976; Harr and Ranken 1973; Hickman 1968, 1976; Holbo and others 1975; Johnson 1978; Johnson and Beschta 1980, 1981; Maser and Trappe 1984b; Miller and others 1976; Paeth and others 1971; Ranken 1974; Rothacher 1965b, 1971, 1973; Rothacher and others 1967; Running and others 1975; Santantonio 1981, 1982; Schoenberger and Perry 1982; Shih and others 1973; Sollins and others 1981b; Swanson and Swanston 1977; Swanston 1974; Swanston and others 1980; Swanston and Swanson 1976; Tarrant 1956a, 1956b; Waring and others 1973, 1978a; Waring and Running 1976; Wells and others 1979; Zobel 1975

Morphology:
Berntsen and Rothacher 1959; Brown 1974; Brown and Parsons 1973a, 1973b; Dyrness 1969, 1973a; Dyrness and Hawk 1972; Edmonds 1974, 1982b; Franklin 1965b; Franklin and Dyrness 1969, 1973; Franklin and others 1972b; Harr and Ranken 1973; Hawk 1973a, 1977; Hawk and Dyrness 1972; Hawk and others 1978; Hawk and Zobel 1974; Hickman 1976; Johnson 1978; Means 1982a; Mills 1983; Paeth 1970; Paeth and others 1971; Rothacher 1965b; Rothacher and others 1967; Sollins and others 1984; Sullivan 1976; Swanson 1980; Swanston 1978, 1981; Swanston and others 1980; Tarrant 1956a, 1956b; Wells and others 1979

Movement (see also erosion, mass movement, and soil disturbance):
Mersereau and Dyrness 1972; Paeth 1970; Paeth and others 1971; Swanson 1979, 1980, 1981; Swanson and Dyrness 1975; Swanson and others 1976a, 1981, 1982a, 1982c; Swanson and Fredriksen 1982; Swanson and James 1975a; Swanson and Sedell 1978; Swanson and Swanston 1977; Swanston 1974, 1976, 1978, 1981; Swanston and others 1980; Swanston and Swanson 1976

Stability:
Dyrness 1967a, 1970, 1975; Fredriksen and others 1975; Mersereau and Dyrness 1972; Mills 1983; Paeth 1970; Paeth and others 1971; Simons and others 1978; Swanson 1979; Swanston 1974, 1976, 1978, 1979, 1981; Swanston and others 1980; Swanston and Swanson 1976; Taskey 1978; Taskey and others 1978

Water flux:
Harr 1977, 1979; Harr and Grier 1976; Harr and Ranken 1973; Harr and Swanson 1980; Shih and others 1973; Sollins and McCorison 1981; Swanson and others 1982a; Swanston 1976

Solar radiation:
Coniferous 1977; Gay 1973; Gregory 1976; Levno and Rothacher 1967; Lyford and Gregory 1975; Naiman and Sedell 1980; Reed and others 1973; Running 1976; Sollins and others 1979; Tucker and Emmingham 1977; Waring 1980a, 1983; Waring and others 1978b; Waring and Running 1976

Solution chemistry (see also nutrients [soils]):
Sollins and others 1980a, 1980b; Sollins and McCorison 1981

Solution transport (see also erosion and soil movement):
Sollins and others 1980b; Swanson and others 1980, 1982a; Swanson and Sedell 1978

Species list (see also taxonomic checklist):
Franklin and Dyrness 1969, 1973; Franklin and others 1972b; Mispagel and Rose 1978; Pike and others 1975; Rhoades 1972; Sherwood and Carroll 1974; Yerkes 1960

Stand ordination:
Dyrness and others 1971, 1976; Franklin and others 1970; McKee 1972; Zobel and others 1973a, 1973b, 1974, 1976

Stem analysis (see also vegetation mapping):
DeMars 1969; DeMars and others 1970; Dyrness 1973a; Franklin and others 1982; Fujimori 1977; Hawk 1973b, 1979; Hawk and others 1978; Herman and DeMars 1970; Herman and others 1975, 1978

Stemflow:
Grier and Cole 1972; Grier and others 1974; Miller and others 1976; Rothacher 1963

Stomatal behavior:
Marshall and Waring 1984; Reed and others 1973; Reed and Waring 1974; Running 1974; Tucker and Emmingham 1977; Waring 1971; Waring and Running 1978; Zobel 1974a, 1975

Storm runoff (see also flood control and stream discharge rate or flow):
Anderson and others 1976; Barnett 1963; Christner 1981; Christner and Harr 1982; Cummins and others 1983; Fredriksen 1965a, 1965b, 1972b; Harr 1976a, 1976b, 1977, 1981; Harr and others 1982; Rothacher 1959, 1973

Storms:
Dale and others 1984; Dyrness 1967b; Fredriksen 1965a; Gratkowski 1956; Rothacher 1963, 1965a, 1973; Rothacher and others 1967; Swanson 1979; Swanson and others 1976a

Stream:

Buffer strips:
Franklin and others 1981; Sedell and Froggatt 1984; Steinblums and others 1984

Communities (see also fish, invertebrates [aquatic], and periphyton):
Anderson and others 1978; Anderson and Sedell 1979; Cummins 1980; Cummins and others 1984; Dudley and Anderson 1982; Franklin and others 1981; Gregory 1983; Hawkins 1981, 1982; Hawkins and others 1982, 1983; Hawkins and Sedell 1981; Lyford and Gregory 1975; McIntire 1971; McIntire and Colby 1978; McIntire and others 1971, 1975; Meehan and others 1977; Minshall and others 1983; Murphy 1978; Murphy and others 1981; Murphy and Hall 1981; Norris and others 1983; Rounick and Gregory 1981; Sedell 1972; Sedell and others 1973, 1982; Triska and Cromack 1980; Triska and others 1982; Vannote and others 1980; Waring 1980c; Wilzbach and Hall 1985

Detritus (see also litter and litterfall [aquatic], and organic matter [streams]):
Aho and others 1973; Anderson and others 1978, 1984a; Anderson and Grafius 1975; Anderson and Sedell 1979; Aumen and others 1983; Cromack and others 1978; Cummins 1980; Cummins and others 1983; Dahm 1984; Dahm and others 1981; Edmonds 1975, 1977; Everest and Meehan 1981; Franklin and others 1981; Grafius 1977; Grafius and Anderson 1979, 1980; Hawkins and others 1982; Hawkins and Sedell 1981; Maser and Trappe 1984b; McIntire and Colby 1978; Meehan and others 1977; Naiman and Sedell 1979a, 1979b, 1980; Pereira and others 1982; Rothacher 1959; Sedell and Dahm 1984; Sedell and others 1973, 1974, 1975, 1978; Sedell and Froggatt 1984; Sollins and others 1985; Speaker and others 1984; Triska and others 1984; Ward 1984

Discharge rate or flow (see also hydrology):
Anderson and others 1976; Brown 1973; Christner 1981; Christner and Harr 1982; Edmonds 1975; Fredriksen 1965a, 1969, 1970; Fredriksen and Harr 1979; Harr 1976a, 1976b, 1977, 1981; Harr and others 1982; Harr and McCorison 1979; Henderson and others 1978; Keller and Swanson 1979; Lienkaemper and Swanson 1980; Rothacher 1965a, 1965b, 1970, 1971, 1973; Rothacher and others 1967; Shih and others 1973; Sollins and others 1980b; Swanson 1979; The Timberman 1957; Triska and others 1982

Functions:
Cummins and others 1984; Dahm 1984; Naiman and Sedell 1980; Sedell and Dahm 1984; Speaker and others 1984; Triska and others 1982; Vannote and others 1980; Waring 1980c

Gradient:
Haer and others 1984; Twkins and others 1983; Murphy and others 1981; Murphy and Hall 1981; Naiman and Sedell 1979a; Sedell and others 1978

Hydrology (see also stream discharge rate or flow):
Christner 1981; Christner and Harr 1982; Harr 1976b; Keller and Swanson 1979; Naiman and Sedell 1979a; Rothacher 1959; Sedell and others 1978

Management:
Cromack and others 1978; Cummins 1980; Frear 1982; Meehan and others 1977; Sedell 1972; Sedell and others 1973, 1982; Sedell and Froggatt 1984; Sedell and Luchessa 1982; Steinblums and others 1984; Swanson and others 1976b; Swanson and Lienkaemper 1978; Swanson and Sedell 1978; Triska and Cromack 1980; Triska and others 1982; USDA, Forest Service, 1958; Waring 1976

Morphology:
Hawkins and others 1983; Keller and Swanson 1979; Meehan and others 1977; Minshall and others 1983; Sedell and others 1978, 1982; Sedell and Luchessa 1982; Swanson and others 1976b, 1980, 1982b; Swanson and Lienkaemper 1978; Swanson and Swanston 1977; Triska and others 1984

Order:
Anderson and others 1978; Cummins and others 1983; Meehan and others 1977; Minshall and others 1983; Naiman and Sedell 1979a, 1979b, 1980, 1981; Sedell and others 1978, 1982; Swanson and others 1982b; Triska and Cromack 1980; Triska and others 1982; Vannote and others 1980

Processes (see also erosion, sediments-sedimentation, and stream discharge rate or flow):
Christner 1981; Cummins and others 1983, 1984; Dahm 1984; Frear 1982; Fredriksen 1963, 1965a; Fredriksen and Harr 1979; Harr 1976b; Keller and Swanson 1979; Levno and Rothacher 1967; Naiman and Sedell 1980; Rothacher 1959; Rounick and Gregory 1981; Sedell and Dahm 1984; Sedell and others 1978; Speaker and others 1984; Swanson 1979, 1980; Swanson and others 1973, 1976b, 1980, 1982a, 1982b; Swanson and Fredriksen 1982; Swanson and Lienkaemper 1978; Swanson and Sedell 1978; Swanston 1974; Ward 1984, 1985

Structure:
Cummins 1980; Hawkins and others 1982, 1983; McIntire and others 1971, 1975; Minshall and others 1983; Sedell 1972; Sedell and others 1973, 1982; Triska and others 1982; Vannote and others 1980; Waring 1973b, 1980c

Substrates:
Gregory 1978; Hawkins and others 1982, 1983; Sedell and Luchessa 1982

Succession (see also forest regeneration):
Cromack and others 1978; Dale and others 1984; Dyrness 1965a; Edmonds 1974, 1975, 1977; Franklin 1979b, 1982a, 1982b; Franklin and Dyrness 1969, 1973; Franklin and others 1982; Franklin and Hemstrom 1981; Franklin and Mitchell 1967; Franklin and Waring 1980; Gholz and others 1977; Harris and others 1982; Hawk 1977; Hawk and Zobel 1974; Hemstrom and Adams 1982; Hemstrom and Franklin 1981; Maser and Trappe 1984b; Means 1982b; Murphy and others 1981; Sherwood and Carroll 1974; Stewart 1984; Sullivan 1978; Swanson 1979; Swanson and others 1982b; Vannote and others 1980; Waring 1973a, 1980c; Yerkes 1958, 1960

Synthesis report (Coniferous Forest Biome):
Aho and others 1973; Edmonds 1974, 1975, 1977, 1982a; Franklin and others 1972a; Waring 1973b; Waring and Edmonds 1974

Taxonomic checklist (see also species list):
Anderson 1976b; Anderson and others 1982; Berntsen and Rothacher 1959; Dudley and Anderson 1982; Franklin and Dyrness 1971; Hickman 1968; Lewis and Maser 1981; Lightfoot 1986; Pike 1972a; Sherwood 1973; Voegtlin 1982

Taxonomy:

Fungi:
Fogel 1975a, 1975b, 1979

Invertebrates:
André 1980; Cooper 1981; Mahmoud 1979; Rausch 1975; Razafimahatratra 1978, 1980; Schwartz 1981; Stonedahl 1982, 1984

Vascular plants:
Franklin 1961b; Hickman 1968

Vertebrates:
Jackman and Scott 1975

Temperature:

Air:

Coniferous 1977; Emmingham 1982; Emmingham and Lundberg 1977; Emmingham and Waring 1977; Gholz 1979, 1982; Grier and Cole 1972; Harr 1981; Harr and Berris 1983; Holbo 1973; McKee and others 1981; Mispagel and Rose 1978; Reed and Waring 1974; Rothacher and others 1967; Running 1976; Sader 1984; Sollins and others 1979; Waring 1971; Waring and others 1978a, 1978b; Waring and Running 1976; Wiens and Nussbaum 1975; Zobel 1971, 1975; Zobel and others 1973b, 1974, 1976

Soil:

Emmingham and Lundberg 1977; Emmingham and Waring 1977; Franklin 1961b, 1963; Harr and Berris 1983; Maser and Trappe 1984b; McBrayer and others 1977; McNabb and Cromack 1983; Miller and others 1976; Reed and Waring 1974; Running and others 1975; Sader 1984; Santantonio 1982; Schoenberger and Perry 1982; Silen 1956, 1960; Sollins and others 1977; Waring and others 1973, 1978a; Waring and Running 1976; The Timberman 1957; Wells and others 1979; Zobel 1971, 1975; Zobel and others 1973b, 1974, 1976

Stress:

Gholz 1978; Gholz and others 1976; Waring and Franklin 1979; Zobel and others 1976

Water:

Fredriksen 1972a; Fredriksen and Harr 1979; Grafius and Anderson 1979, 1980; Gregory 1976; Levno and Rothacher 1967, 1969; Meehan and others 1977; Rothacher and others 1967; Sedell and others 1973

Timber harvesting:

Anderson and others 1976; Berntsen and Rothacher 1959; Brown 1973; Carkin and others 1978; Carow 1959; Carow and Ruth 1957; Carow and Silen 1957; Christner and Harr 1982; Dale and others 1984; Dealy 1959; Dyrness 1965a, 1965b, 1966, 1967c, 1973b; Edmonds 1974, 1975; Forest Industries 1962; Franklin 1965a; Fredriksen 1970, 1971, 1972a; Fredriksen and others 1975; Fredriksen and Harr 1979; Gashwiler 1959; Gholz and others 1977; Harr 1976a, 1976b, 1981; Harr and others 1982; Harr and McCorison 1979; Harris and others 1982; Johnson 1978; Johnson and Beschta 1980; Krzak 1980; Larson 1981; Levno and Rothacher 1967, 1969; Marion 1981; Mersereau and Dyrness 1972; Murphy and Hall 1981; Rice and others 1972; Rothacher 1965b, 1970, 1971, 1973; Ruth and Silen 1950; Sedell and others 1973, 1982; Silen 1955; Sollins and McCorison 1981; Sullivan 1976, 1978; Swanson 1979; Swanson and Dyrness 1975; Swanson and others 1976a, 1981; Swanson and Lienkaemper 1978; Swanson and Sedell 1978; Swanston 1974, 1976; Swanston and Swanson 1976; The Timberman 1957; Tucker and Emmingham 1977; Waring 1976; Wustenberg 1954; Yerkes 1958, 1960

Topography:

Berntsen and Rothacher 1959; Boyce and Wagg 1953; Franklin 1965b; Franklin and Dyrness 1969, 1973; Franklin and others 1972b; Fredriksen 1970; Hawk 1977; Hickman 1968; Steinblums and others 1984; Sullivan 1976; Swanson and James 1975a, 1975b; Waring 1982

Transpiration (see also evaporation):
Anderson and others 1976; Edmonds 1975; Emmingham 1982; Harr 1979; Harr and others 1982; Kline and others 1972, 1973, 1976; Meentemeyer 1977; Reed and Waring 1974; Rothacher 1971; Running and others 1975; Shih and others 1973; Waring 1971, 1973a, 1973b; Waring and Edmonds 1974; Waring and others 1973; Waring and Running 1976, 1978; Webb and others 1978, 1983; Zobel 1974a

Tree:

Diameter:
Hemstrom and Adams 1982; Means 1982a; Stewart 1984; Waring 1982; Waring and Franklin 1979

Mortality (see also fallen trees, seedling growth and survival, windthrows, and woody debris):
Franklin 1982a; Franklin and others 1982; Franklin and Mitchell 1967; Graham 1981a, 1981b; Hemstrom and Adams 1982; Means 1982a; Waring 1980b, 1980c, 1983

Planting:
Anderson and others 1976; Berntsen 1958; Rothacher and Franklin 1964

Vigor:
Waring 1980b, 1980c, 1983

Trophic relations:
Aho and others 1973; Carroll 1980; Colby and McIntire 1978; Cummins 1980; Gregory 1983; Hawkins and Sedell 1981; Mispagel and Rose 1978; Murphy and others 1981; Norris and others 1983; Sedell and others 1973; Strand 1973a; Warren 1971; Wilzbach and Hall 1985

Vegetation:

Mapping (see also stem analysis):
Dyrness 1973a; Dyrness and Hawk 1972; Hawk 1973b, 1979; Hawk and Dyrness 1972

Plot data:
Means 1980, 1982a

Study:
Campbell and Franklin 1979; Dyrness 1965a, 1973a, 1973b; Dyrness and Hawk 1972; Franklin and Dyrness 1969, 1971, 1973; Hawk 1973a; Hickman 1968, 1976; Miles 1983; Yerkes 1960

Zones (see also forest zones):
Gholz 1979, 1982; Grier and Running 1977; Waring and Edmonds 1974; Zobel and others 1974, 1976

Vertebrate biology:
Forsman 1976, 1980; Forsman and others 1984; Gashwiler 1959, 1961, 1963, 1965a, 1965b, 1970b, 1971a, 1977, 1979; Gashwiler and Ward 1966, 1968; Hawkins and others 1983; Jackman and Scott 1975; Maser and others 1978a, 1978b; McCullough 1964; Nussbaum and Clothier 1973; Nussbaum and Maser 1975; Parsons 1975; Peacock and Nussbaum 1973; Ure and Maser 1982; Whitaker and others 1977; Whitaker and Maser 1976; Wiens and Nussbaum 1975; Wilzbach and Hall 1985; Wyatt 1959

Water:

Balance (plants):

Gholz 1979, 1982; Grier and Running 1977; Long 1982; Sollins and others 1980a; Waring 1985

Conductance (plants (see also water flux):

Edmonds 1975, 1977; Kline and others 1972, 1973, 1976; Running 1976; Running and others 1975; Waring and others 1977, 1982; Waring and Running 1976, 1978

Cycling:

Coniferous 1977; Edmonds 1974, 1975, 1977; Franklin and others 1981; Fredriksen and Harr 1979; Sollins and others 1974, 1979, 1980b, 1982; Waring 1973b; Waring and Edmonds 1974; Waring and others 1980

Flux (conifers) (see also water conductance):

Running and others 1975; Waring and others 1973; Waring and Running 1976

Quality (streams):

Anderson and others 1976; Brown 1973; Cushing and others 1980; Edmonds 1974, 1975; Fredriksen 1971, 1972a; Fredriksen and others 1975; Fredriksen and Harr 1979; Minshall and others 1983; Moore and others 1974; Naiman and Sedell 1979a, 1980; Rothacher and others 1967; Sedell and others 1975; Sollins and McCorison 1981; Triska and others 1984; Triska and Sedell 1976

Relations (plants) (see also sapwood water storage, water balance, and water conductance):

Edmonds 1977; Grier and others 1978; Howe 1978; Running and others 1975; Waring 1985; Waring and others 1980; Webb and others 1978

Sampling:

Fredriksen 1969

Yield (streams) (see also stream discharge rate or flow):

Anderson and others 1976; Brown 1973; Harr 1976a, 1979; Harr and others 1982; Rothacher 1970, 1971

Watershed management (see also forest management and stream management):

Anderson and others 1976; Barnett 1963; Berntsen and Rothacher 1959; Franklin and others 1981; Fredriksen 1971; Hall and others 1978; Harr 1976a, 1976b; Murphy and Hall 1981; Naiman and Sedell 1981; Rice and others 1972; Swanson 1981; Swanson and others 1982a, 1982c; Swanson and Fredriksen 1982; Swanston 1974, 1976, 1978, 1979, 1981; Swanston and others 1980; USDA, Forest Service, 1958

Weathering:

James 1977; Sollins and others 1980b

Wildfire:

Burke 1979; Stewart 1984; Swanson 1981

Wildlife management:
Dealy 1959, 1966; Forsman and others 1984; Harris 1984a, 1984b; Harris and others 1982; Jackman and Scott 1975; Nussbaum and Maser 1975; Ruggiero and Carey 1984; The Timberman 1957; USDA, Forest Service, 1958

Windthrows (see also fallen trees and woody debris):
Graham 1981a, 1981b; Gratkowski 1956; Steinblums and others 1984

Woody debris:

Streams (see also fallen trees and organic matter [streams]):
Aumen and others 1983; Cromack and others 1978; Cummins 1980; Cummins and others 1983; Dudley and Anderson 1982; Everest and Meehan 1981; Franklin 1982b; Franklin and others 1981; Frear 1982; Fredriksen 1963, 1965a; Harmon and others 1986; Harr 1976b; Hawkins and others 1983; Keller and Swanson 1979; Levno and Rothacher 1967, 1969; Lienkaemper 1976; Lienkaemper and Swanson 1980; Maser and Trappe 1984b; Naiman and Sedell 1979a, 1979b; Pereira and others 1982; Rothacher 1959; Sedell and others 1973, 1982; Sedell and Luchessa 1982; Speaker and others 1984; Swanson and others 1976, 1980, 1982b; Swanson and Lienkaemper 1978; Swanson and Sedell 1978; Swanson and Swanston 1977; Swanston 1974, 1976; Triska and Cromack 1980; Triska and others 1982, 1984; Triska and Sedell 1976; Waring 1980c

Terrestrial (see also fallen trees and windthrows):
Cline and Phillips 1983; Franklin 1982a, 1982b; Franklin and others 1981; Franklin and Waring 1980; Graham 1981a, 1981b; Grier and Logan 1977; Harmon and others 1986; Maser and others 1978b; Means and others 1981, 1984, 1985; Sollins and others 1980b; Strand and Grier 1973; Thomas and others 1979; Triska and Cromack 1980; Waring 1980c

McKee, Arthur; Stonedahl, Gary M.; Franklin, Jerry F.; Swanson, Frederick J., comps. 1987. Research publications of the H.J. Andrews Experimental Forest, Cascade Range, Oregon, 1948 to 1986. Gen. Tech. Rep. PNW-GTR-201. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 74 p.

A list of publications resulting from research at the H.J. Andrews Experimental Forest, Willamette National Forest, Oregon, from 1948 to 1986 is presented. Nearly 600 publications are listed, including papers, theses, and abstracts. An index is provided that cross-references the listings under appropriate keywords.

Keywords: Bibliographies (forestry), Oregon (H.J. Andrews Exp. For.), H.J. Andrews Exp. For.--Oregon.

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General Technical
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PNW-GTR-202

The Timber Resource Inventory Model (TRIM):

A Projection Model for Timber Supply and Policy Analysis

P.L. Tedder, Richard N. La Mont, and Jonna C. Kincaid

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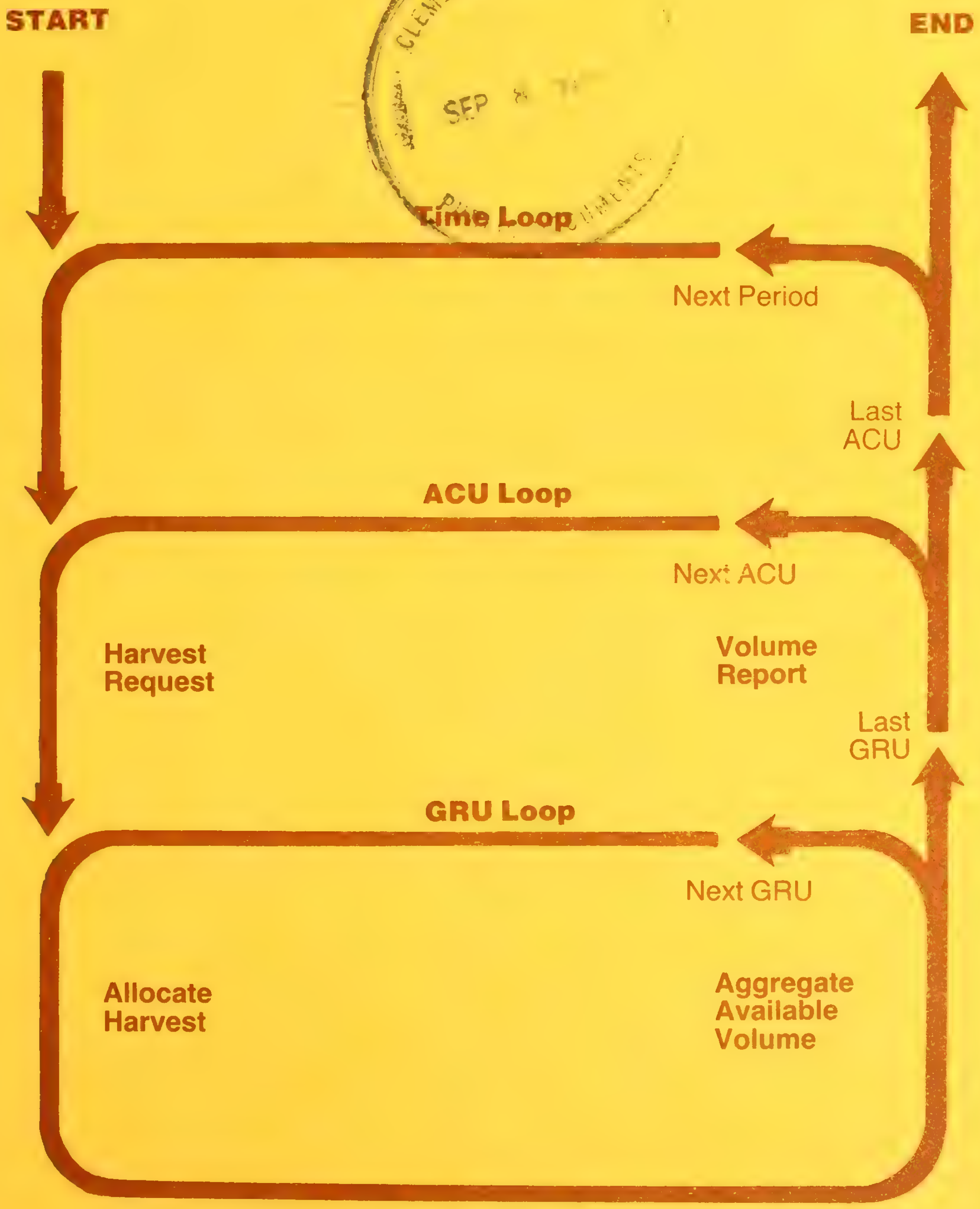

Authors

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July 1987

Abstract

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TRIM (Timber Resource Inventory Model) is a yield table projection system developed for timber supply projections and policy analysis. TRIM simulates timber growth, inventories, management and area changes, and removals over the projection period. Programs in the TRIM system, card-by-card descriptions of required inputs, table formats, and sample results are presented. The programs are available from the Pacific Northwest Research Station.

Keywords: Computer programs/programing, models, timber inventory, timber supply, projections (supply/demand), simulation.

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Introduction

The timber resource inventory model (TRIM) is a yield table projection system designed and developed to model forest inventory changes over time in response to different levels of management and to removals from either large or small forested areas.

TRIM is a series of four computer programs: BRUSCN processes the initial inventory; GRUSCN processes yield and management information; ACUSCN processes organization and removals information and appropriately matches the information produced by the first two programs; and the final program, TRIM, uses the computer data base file created in ACUSCN to simulate growth, yield, management changes, and removals over the length of the simulation.

TRIM requires data input at three levels: (1) initial inventory for BRUSCN; (2) yield and management for GRUSCN; and (3) organization and removals for ACUSCN. Figure 1 illustrates the three levels of input. The initial inventory is specified in a BRU (basic resource unit), which contains unstocked acres, donor acres, and timberland acres. In figure 1, there are six BRU's, each of which represents a different location and site. A GRU (grouped resource unit) provides the data necessary

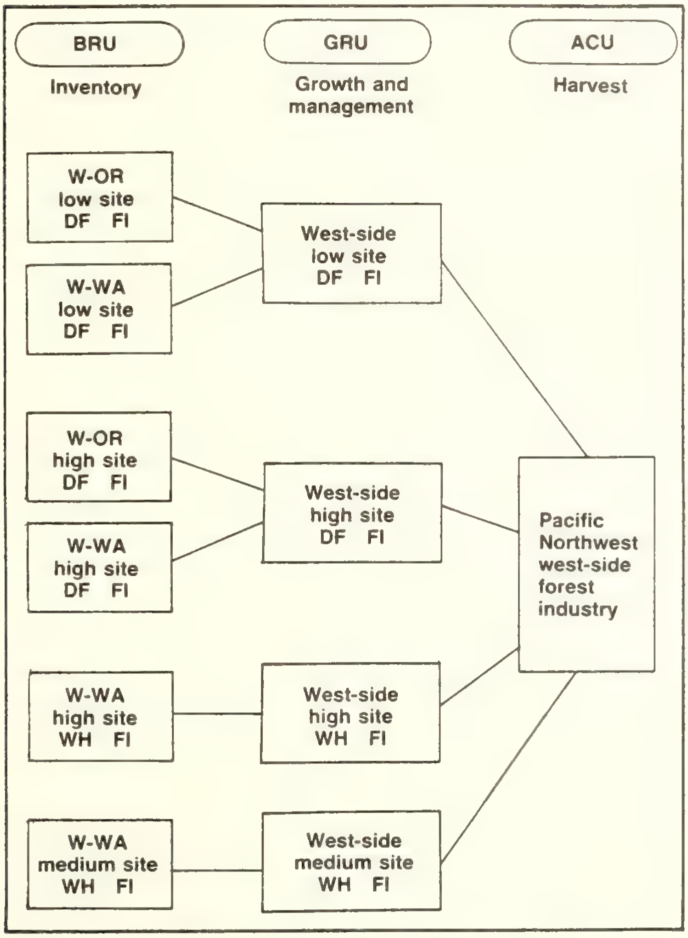

Figure 1—Example of BRU, GRU, and ACU aggregation.

to simulate yield and management for the initial inventory and for future inventories. The GRU contains either one or a group of BRU's that are summed to provide a combined GRU-level inventory, which is the most detailed subdivision recognized by the TRIM program. After BRU's are summed into a GRU, further identification of the BRU is not possible. Growth and management options provided at the GRU level apply, as well, to this combined inventory. Some types of information needed for a GRU are the BRU membership list, volume yield tables by age class and management intensity, volume unit conversion factors, specifications for shifting acres to and from donors and among management intensities, treatment options (such as precommercial and commercial thinning and fertilization), regeneration options, and revenue and cost data for economic reports. In figure 1, the first two GRU's have two BRU's assigned to them; the last two GRU's have only one BRU each.

A collection of GRU's comprise an ACU (allowable cut unit). ACU information includes the GRU membership list, harvest requests, and labels for treatments, management intensities, sites, and species types. In figure 1, all four GRU's are grouped into the single ACU.

TRIM System Details

TRIM simulations can require large amounts of data as inputs. This possibility and the need for detailed checking for errors led to development of the three models, BRUSCN, GRUSCN, and ACUSCN. These three models are data processing programs that scan all input values, flag illegal or unusual values, provide default values automatically, and print compact reports. Figure 2 illustrates how each program processes its own data input and how it supplies the appropriate information for the next step in the process. At the BRU level, the initial inventory data is read by BRUSCN, is processed into a BRURAF (a RAF is a random access file), and is available when the ACUSCN model is run. At the GRU level, the management data is read by GRUSCN, is processed into a GRURAF, and is available when the ACUSCN model is run. As indicated by figure 2, the BRUSCN and GRUSCN models are run independently of each other. For example, if there is a mistake in one of the BRU's, GRUSCN would not have to be run again, just BRUSCN. Or, if you wanted to change yield tables in several GRU's, only a rerun of the GRUSCN model would be necessary. At the ACU level, harvest data are read by ACUSCN, are processed into another random access file called BIGRAF, and are ready for a TRIM run. If changes are made in a BRURAF or GRURAF or in the harvest data input for ACUSCN, ACUSCN would have to be run again. There are therefore, four computer runs that must be made to complete a TRIM simulation. If, however, data changes in only the harvest requests were made, only the ACUSCN and TRIM would need to be run again. In the course of making large simulations, alternate runs of any programs can create multiple data and RAF's on the computer. The TRIM system provides a date and time for efficient record keeping for all RAF's created with the four programs.

BRUSCN

The BRUSCN program (fig. 3) has a relatively simple structure. For each BRU, the program reads from file INVEN, prints, and checks the input data. It then computes inventory totals, writes the data on a random access file called BRURAF, and prints a compact report on file LIST. After all BRU's have been scanned, the program sorts the list of BRU's and their file locations into ascending order and writes the sorted list on BRURAF. The creation date and time, BRU count, and locations of

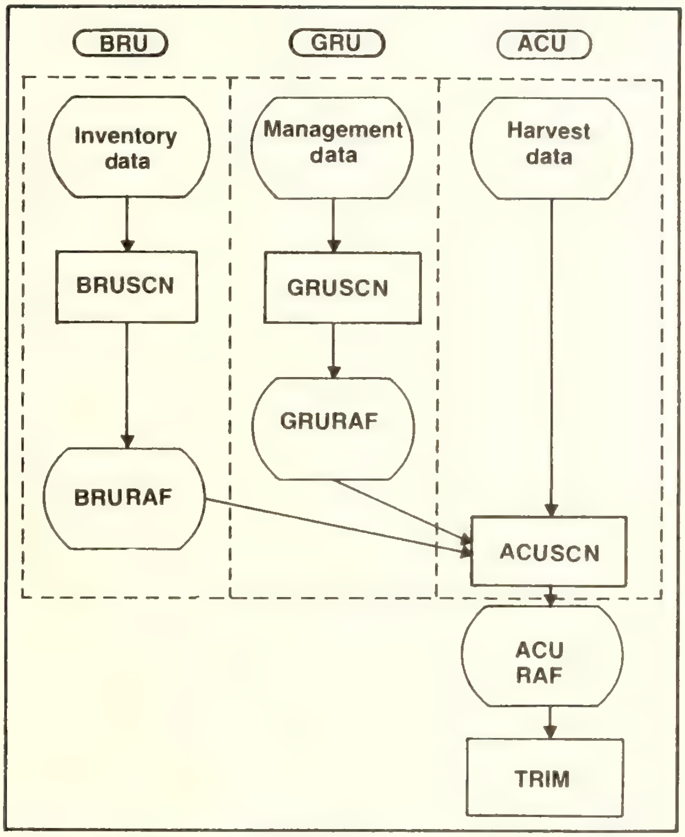

Figure 2—BRU, GRU, and ACU program file processing steps.

the list are written on the BRURAF key record. BRUSCN also prints the sorted BRU list. This output organization permits easy access by other programs. Appendix A contains a detailed synopsis of BRUSCN.

GRUSCN

The GRUSCN program (fig. 4) is quite similar in structure to BRUSCN. GRUSCN reads from file CONTROL, prints, checks input data for each GRU, provides default values, and cross-checks among sets of related data. One particularly convenient feature of GRUSCN is the fill value, a single value used to fill all unspecified entries of a sequence by period or age class. If a constant discount rate, for example, is required for all periods of the simulation, the fill value for the discount rate should be set to the selected value and the program will automatically use that value in the discount rate variable for all periods. A sequence of mortality volumes per acre could similarly be specified for age classes 0 to 4, and the fill value used to provide mortality volumes for all other age classes.

All specified and default values are written to a random access file called GRURAF. A compact report of all specified and default values are also written on a file called LIST that can be printed and inspected for errors. After all GRU's have been scanned, the program sorts the list of GRU's and their file locations, writes the sorted list and the key information on GRURAF, and prints the sorted GRU list. Appendix B contains a detailed synopsis of GRUSCN.

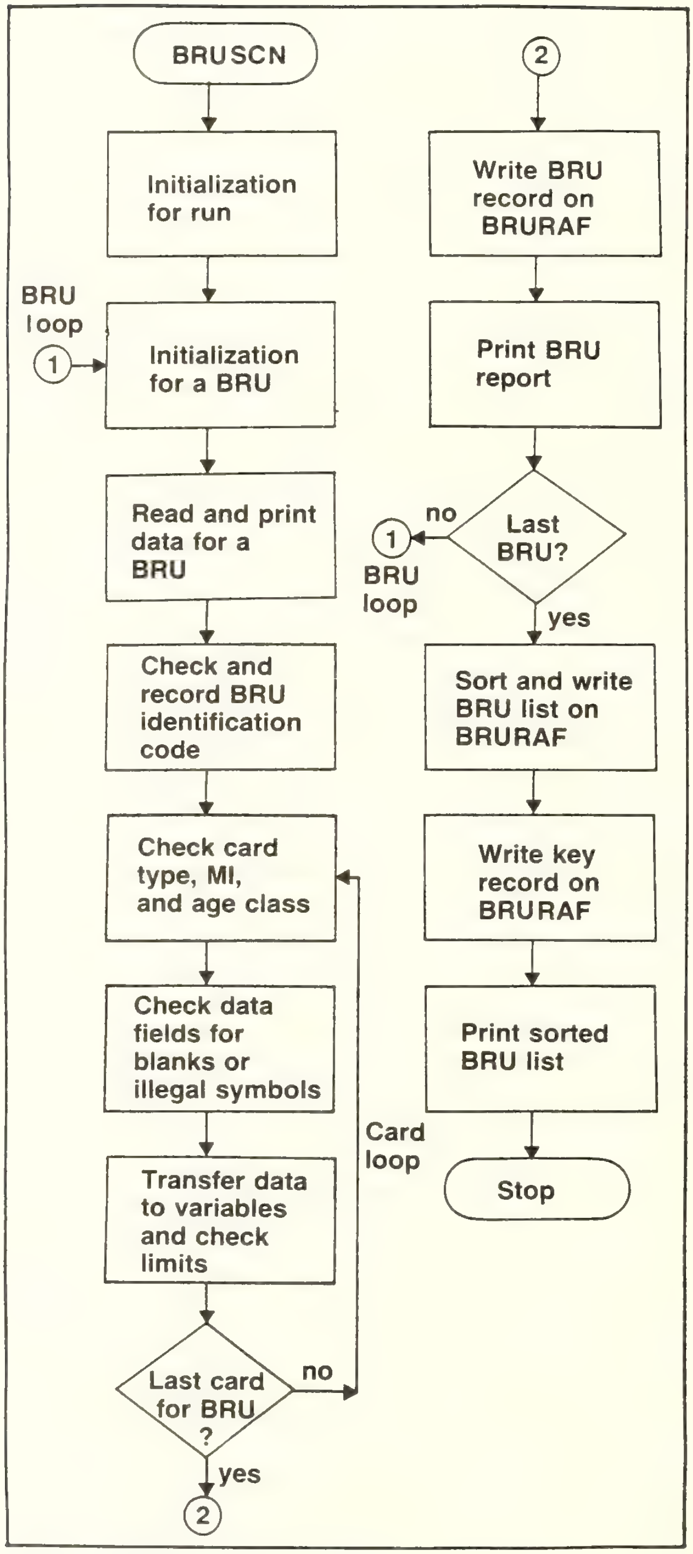
BRUSCN
Initialization for run
BRU loop
1
Initialization for a BRU
Read and print data for a BRU
Check and record BRU identification code
Check card type, MI, and age class
Check data fields for blanks or illegal symbols
Transfer data to variables and check limits
Last card for BRU ?
no
yes
2
Card loop
2
Write BRU record on BRURAF
Print BRU report
Last BRU?
no
1
BRU loop
yes
Sort and write BRU list on BRURAF
Write key record on BRURAF
Print sorted BRU list
Stop

Figure 3—BRUSCN logical flow outline.

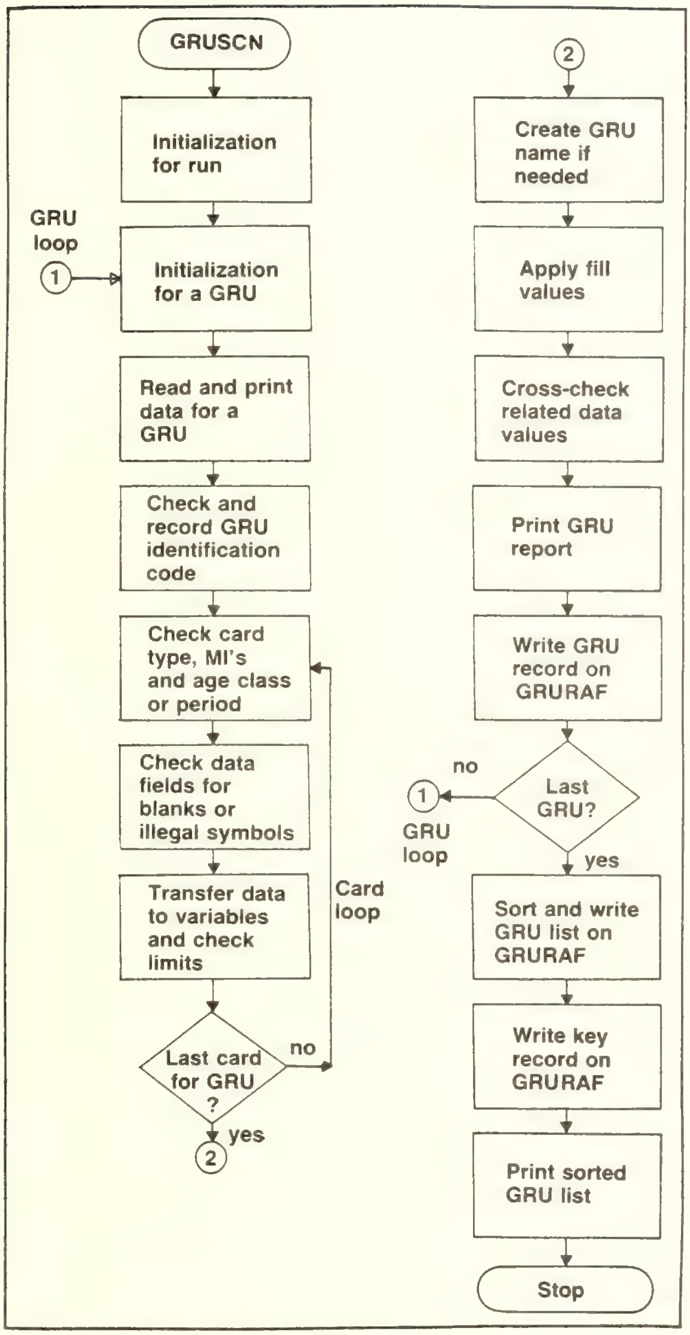
GRUSCN
Initialization for run
GRU loop
1
Initialization for a GRU
Read and print data for a GRU
Check and record GRU identification code
Check card type, MI's and age class or period
Check data fields for blanks or illegal symbols
Transfer data to variables and check limits
Card loop
Last card for GRU ?
no
yes
2
2
Create GRU name if needed
Apply fill values
Cross-check related data values
Print GRU report
Write GRU record on GRURAF
Last GRU?
no
1
GRU loop
yes
Sort and write GRU list on GRURAF
Write key record on GRURAF
Print sorted GRU list
Stop

Figure 4—GRUSCN logical flow outline.

ACUSCN

The ACUSCN program (fig. 5) reads from file HEADER, prints, checks the general run information and the data for each ACU, and links the three levels of data. BRURAF and GRURAF must be provided to ACUSCN to accomplish this linkage. When the data for an ACU have been read, printed, and checked, ACUSCN uses the sorted GRU list to find the data for GRU's belonging to the ACU and uses the sorted BRU list to find the data for BRU's belonging to the GRU's. Inventory data are summed for BRU's and reported for each GRU. The GRU growth and management data and the summed inventory are written to a random access file called BIGRAF. After all GRU's in an ACU have been processed, ACUSCN writes the ACU data, which includes the file locations of its GRU's, to BIGRAF. The BIGRAF key record contains the general run information and the file locations of each ACU. ACUSCN prints a tree that shows the relationships of each ACU, GRU, and BRU. Besides the tree report, a report of the BRU's and GRU's and their usage in the simulation is provided. Appendix C contains a detailed synopsis of program ACUSCN.

TRIM

Program TRIM (fig. 6) uses the coordinated data on BIGRAF to perform the simulation requested. The accompanying flowchart shows the triple-loop structure of TRIM. The outer time loop is measured in periods and starts at time zero. The middle ACU loop reads ACU data from BIGRAF and sets summary variables to zero. The inner loop is where GRU's are processed. In period zero, the GRU data are read from BIGRAF, and the summary values, including the harvest from the previous period, are set to zero. This zero harvest is subtracted from the inventory. Cutover and unstocked acres are regenerated and land shifts are made to and from donors and among management intensities. The inventory is summed into report groups. Precommercial thinning and fertilization are done. Volume per acre and total volume are projected for the end of the period by using either the yield table or approach-to-normal-volume-growth methods described in card 30 of the card-by-card description section. Growth is calculated by subtracting volume after harvest and land base shifts from volume at the end of the period. The exogenous harvest (conversion, commercial thinning, and mortality salvage) are taken, the available harvest aggregated, and updated GRU information stored on a binary random access file called CURRAF. After all GRU's for an ACU have been processed in the GRU loop, the harvest proportions are assigned to each GRU and the ACU sums are stored on CURRAF. After all ACU's are processed in the ACU loop, the zero period is complete.

For subsequent periods, GRU data are read from both BIGRAF and CURRAF, and the harvest that was computed at the end of the previous period is subtracted from the inventory. The GRU detailed reports for the previous period are then written. At this point, the GRU loop retraces the path taken in the zero period; that is, land base shifts, inventory summing, precommercial thinning and fertilization, projection of new inventory, calculation of growth, exogenous harvest, available harvest aggregation, and storage of information on CURRAF.

The only added tasks in the ACU loop for subsequent periods are writing ACU detailed reports for the last period and storing ACU summary report information. Because the report writing occurs in the period after the GRU's were processed, the final period must produce two sets of reports and process the GRU's an additional time.

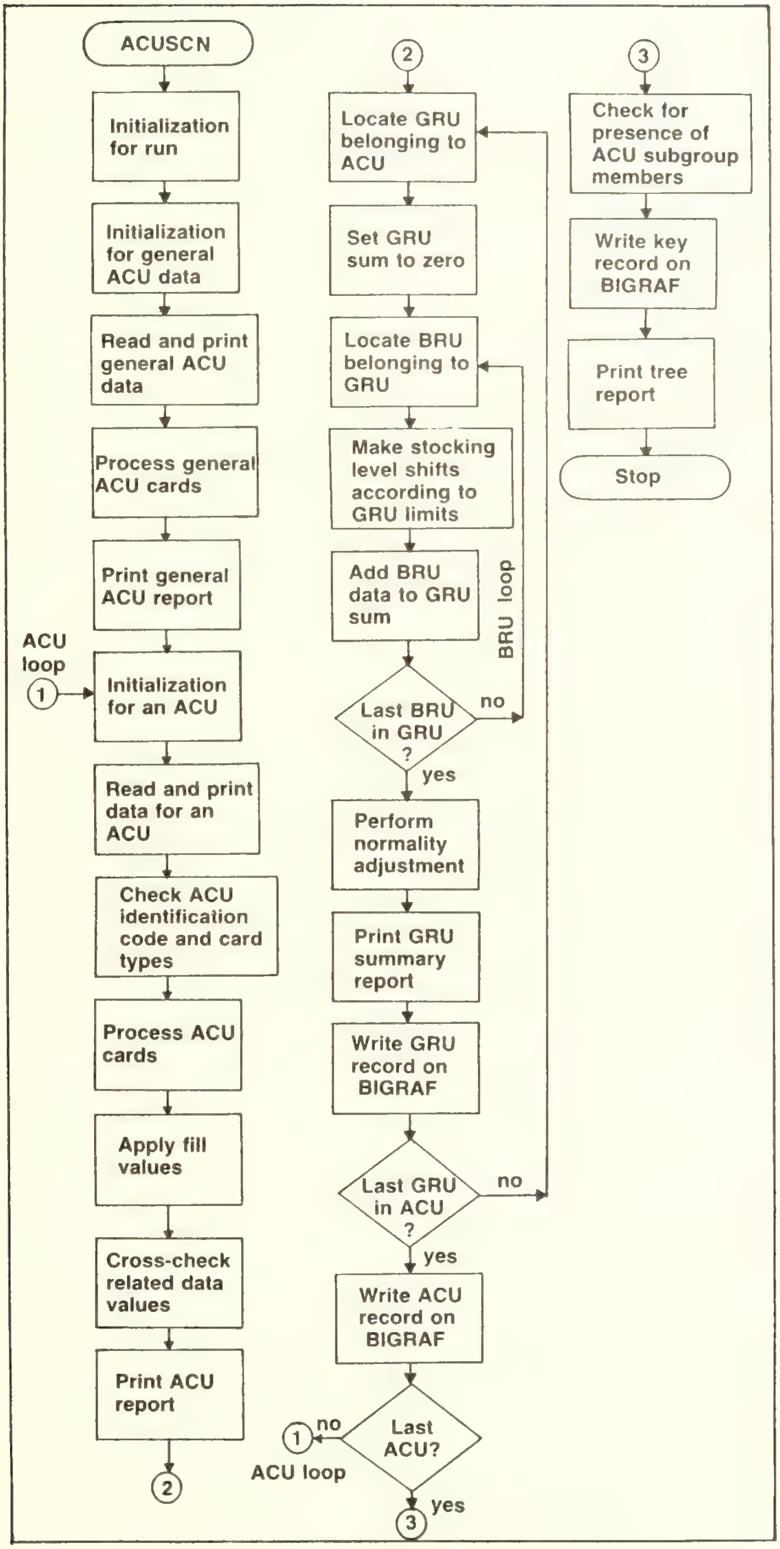
ACUSCN
Initialization for run
Initialization for general ACU data
Read and print general ACU data
Process general ACU cards
Print general ACU report
ACU loop
1
Initialization for an ACU
Read and print data for an ACU
Check ACU identification code and card types
Process ACU cards
Apply fill values
Cross-check related data values
Print ACU report
2
2
Locate GRU belonging to ACU
Set GRU sum to zero
Locate BRU belonging to GRU
Make stocking level shifts according to GRU limits
Add BRU data to GRU sum
BRU loop
Last BRU in GRU ?
no
yes
Perform normality adjustment
Print GRU summary report
Write GRU record on BIGRAF
Last GRU in ACU ?
no
yes
Write ACU record on BIGRAF
Last ACU?
no
1
ACU loop
yes
3
3
Check for presence of ACU subgroup members
Write key record on BIGRAF
Print tree report
Stop

Figure 5—ACUSCN logical flow outline.

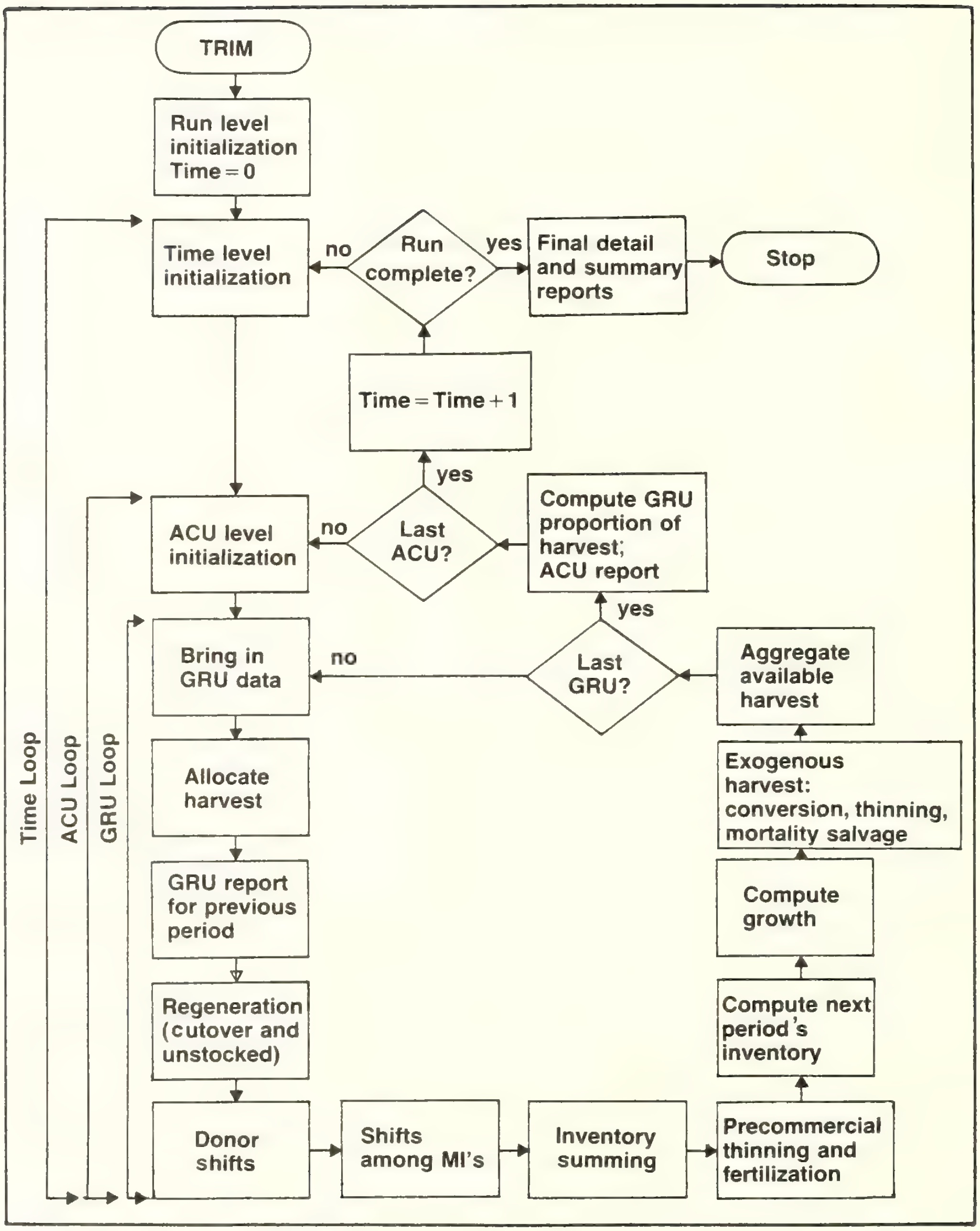
TRIM
Run level initialization Time = 0
Time level initialization
no
Run complete?
yes
Final detail and summary reports
Stop
Time = Time + 1
yes
ACU level initialization
no
Last ACU?
Compute GRU proportion of harvest; ACU report
yes
Bring in GRU data
no
Last GRU?
Aggregate available harvest
Allocate harvest
Exogenous harvest: conversion, thinning, mortality salvage
GRU report for previous period
Compute growth
Regeneration (cutover and unstocked)
Compute next period's inventory
Donor shifts
Shifts among MI's
Inventory summing
Precommercial thinning and fertilization
Time Loop
ACU Loop
GRU Loop

Figure 6—TRIM logical flow outline.

TRIM writes six types of reports with detailed and summary forms for each type.

1. The inventory report provides inventory acres, average diameter of the inventory, standing inventory volume after harvest (before growth), and growth volume. The detailed report breaks this information down by age class report group and management type (management intensity plus stocking level for management intensity 1). All volume is reported in the base volume measure.

2. The harvest report for the base yield provides harvested acres, average diameter of the harvest, and volumes for final harvest, commercial thinning, mortality salvage, and conversion. The detailed report breaks this information down by age class report group and management intensity.

3. Alternate volume measure report for inventory and harvest; if volume conversion factors are specified for GRU's, this report will generate reports 1 and 2 in the volume measure specified.

4. The regeneration/cultural treatment report provides regeneration acres from cut and unstocked sources and acres precommercially thinned, commercially thinned, and fertilized. The detailed report breaks this information down by management intensity, planting stock (regular and genetic), stand entry, and application.

5. The detailed economic report provides soil expectation values by management intensity and age class, regeneration costs by planting stock, and dollar values for cost, revenue, and net value by management intensity and seven treatment categories. The seven categories are regeneration, precommercial thinning, fertilization, commercial thinning, mortality salvage, final harvest, and total. Conversion is considered a final harvest. The summary economic report provides net dollar values for the seven categories.

6. The land shift report lists acres that move to and from donors and among management intensities. The detailed report lists (a) donor acres to and from the timberland inventory and the net change in acres for donors and management intensities; (b) timberland acres for management intensity source and recipient; and (c) shifting results by management intensity and donor and by five categories. The five categories are starting area, net area change for donors, net area change for management intensities, total net area change, and ending acres. The summary report gives the ending acres for management intensities and donors.

Detailed reports are available for GRU's and ACU's. Summary reports are available for ACU's, ACU subgroups, and totals over all ACU's. Appendix D contains a detailed synopsis of program TRIM.

Procedure for Running the TRIM System

BRUSCN, GRUSCN, ACUSCN, and TRIM must be initially run in the listed order to complete a full simulation with the entire TRIM system. The following represents the procedure to follow.

BRUSCN

1. Ready input file. The formatted data file INVEN contains BRU's that will be used with the GRU's. The BRU identification must be the same as the membership list in the GRU's.

2. Execute BRUSCN.

3. Results of BRUSCN.

   A. Output file, screen display—this informs user of the program's progress and, if there were any errors, where they were detected during execution.

   B. Output file, BRURAF—this binary random access data file contains all processed BRUs. This file will be read by the ACUSCN program.

   C. Output file, LIST—this formatted output file contains the compact BRU-by-BRU reports. All error messages written by the program will appear immediately beneath the card image of each BRU.

   D. Output file, QUIZ—this file is only present if there are no errors detected in the run. This file can be used to communicate to the computer operating system that an error-free run occurred.

4. Analysis of BRUSCN results. The screen display and the QUIZ file will inform the user of the run results. If no errors are detected, the user can proceed to the GRUSCN or ACUSCN program. If errors are reported, the following outline should aid in debugging:

   A. Edit/print the LIST file. At the bottom of the file a compiled list of all BRU's is reported. Any BRU with an error will be flagged by an asterisk.

   B. Record the flagged BRU's and locate them in the upper portion of the file. The BRU's are processed sequentially in the same order as the INVEN file; for every BRU there is a report of the card images, errors (if any), and compiled data.

   C. The error messages will inform the user of the record number in the INVEN file, card type, and data field. Correct the error.

   D. Prior to rerunning BRUSCN, be sure to delete/remove unneeded output files, BRURAF, QUIZ, and LIST. RAF's with errors will cause error messages in the ACUSCN program.

   E. Rerun BRUSCN.

GRUSCN

1. Ready input file. The formatted data file CONTROL, contains GRU's that will be used with the ACU's. The GRU identification must be the same as the membership list in the ACU's.

2. Execute GRUSCN.

3. Results of GRUSCN.

   A. Output file, screen display—informs user of the program's progress and, if there were any errors, where they were detected during execution.

   B. Output file, GRURAF—binary random access data file contains all processed GRU's. This file will be read by the ACUSCN program.

   C. Output file, LIST—formatted output file contains the compact GRU-by-GRU reports. All error messages written by the program will appear immediately beneath the card image of each GRU.

   D. Output file, QUIZ—this file is only present if no errors are detected in the run. This file can be used to communicate to the computer operating system that an error free run occurred.

4. Analysis of GRUSCN results. The screen display and the QUIZ file will inform the user of the run results. If no errors are detected, the user can proceed to BRUSCN or ACUSCN. If errors are reported, the following outline should aid in debugging:

   A. Edit/print the LIST file. At the bottom of the file, a compiled list of all GRU's is reported. Any GRU with an error will be flagged by an asterisk.

   B. Record the flagged GRU's and locate them in the upper portion of the file. The GRU's are processed sequentially in the same order as the CONTROL file, and for every GRU there is a report of the card images, errors (if any), and compiled data.

   C. The error messages will inform the user of the record number in the CONTROL file, card type, and data field. Correct the error.

   D. Prior to rerunning GRUSCN, be sure to delete/remove unneeded output files, GRURAF, QUIZ, and LIST. RAF's with errors will cause error messages in the ACUSCN program.

   E. Rerun GRUSCN.

ACUSCN

1. Ready input file.

   A. HEADER—this formatted data file contains general run data and ACU data.

   B. BRURAF—this binary random access data file contains the BRU data that will be used with the GRU's.

   C. GRURAF—this binary random access data file contains the GRU data that will be used with the ACU's.

2. Execute ACUSCN.

3. Results of ACUSCN.

   A. Output file, screen display—informs user of the program's progress and whether any errors were detected during execution.

   B. Output file, BIGRAF—binary random access data file contains all processed ACU's, GRU's, and BRU's. BIGRAF will be read by the TRIM program.

   C. Output file, LIST—formatted output file contains the compact ACU-by-ACU reports. Within the ACU report there are several reporting types including a report of the card images, a compact listing of the cards, BRU normality, GRU inventory, and GRU normality. All error messages are written under the general and ACU card-image listing.

   D. Output file, QUIZ—file is only present if there are no errors detected in the run. This file can be used to communicate to the computer operating system that an error-free run occurred.

4. Analysis of ACUSCN results. The screen display and the QUIZ file will inform the user of the run results. If no errors are detected, the user can proceed to the TRIM program. If errors are reported, the following outline should aid in debugging:

   A. Edit/print the LIST file. At the bottom of the ACU HEADER card images and each individual ACU card image, the total number of errors are reported. Besides the general and ACU card error messages, there is error reporting of problems in combining BRU's into GRU's and problems combining GRU's into ACU's.

   B. Record these general and ACU card errors and then locate them in the upper portion of the file. The ACU's are processed sequentially in the same order as the HEADER file.

   C. The error messages will inform the user of record number in the HEADER file, card type, and data field. Correct any error.

   D. Record the errors from combining both BRU's and GRU's. These errors are usually caused by mistakes in the numbering system for BRU's, GRU's, or ACU's. Check the INVEN and CONTROL file and be sure that the correct RAF's are present. Also check the INVEN, CONTROL, and HEADER for the numbering system. Errors in the number system may require rerunning GRUSCN, BRUSCN, ACUSCN, or all three programs.

E. Prior to rerunning ACUSCN or associated programs, be sure to delete/remove unneeded output files, BIGRAF, QUIZ, and LIST. A RAF with errors will cause error messages in the TRIM program.

F. Rerun ACUSCN.

TRIM

1. Ready input file. BIGRAF—this binary random access data file contains the BRU, GRU, and ACU data that will be used in the TRIM simulation.

2. Execute TRIM.

3. Results of TRIM.

A. Output file, screen display—informs user of the program's progress and if any errors were detected during execution.

B. Output file, CALLS—formatted output file contains a detailed reporting of all subroutines entered and any WARNING or CATASTROPHIC error messages. All error messages are written under the subroutine report.

C. Output file, DETAIL—formatted output file contains all reports that were requested in the report matrix in the HEADER general card data.

D. Output file, DUMP—formatted output file contains reports that were requested by the dump flag in the GRU card data. If a TRIM self-detected error (CATASTROPHIC) occurs, the dump flag is automatically turned on and those reports are written.

4. Analysis of TRIM results. The screen display and the STOP statement will inform the user of the results of the run. If no errors are detected, the user can review the reporting in the DETAIL file. If errors are reported, the following outline should aid in debugging:

A. Edit/print the CALLS file. The last error (CATASTROPHIC) message will appear at the bottom of the file.

B. Record the GRU and ACU where the error occurred and review the assumptions within that unit.

C. The error messages will inform the user of the subroutine and type of error that occurred. If insight is not gained from reviewing the assumptions, a programmer and the FORTRAN source code may be needed.

D. Prior to rerunning TRIM, be sure to delete/remove unneeded output files, CALLS, DETAIL, and DUMP.

E. Rerun TRIM.

Card-by-Card Descriptions

The following section is a card-by-card description of each input in the TRIM system. BRU cards are presented first and are followed by GRU cards and ACU cards. Reference to the card-by-card formats located in appendix E may be helpful in reviewing this section.

BRU Card Descriptions

BRU Card Type 1, Unstocked Acres

Item(s): Unstocked acres in BRU.

Simple real variable: UNSBRU.

Default: No acres in the unstocked category.

Limits: Nonnegative and less than 1 billion and only one card.

Description: Initial pool of acres designated unstocked that are not in the productive timberland base. Acres shifted to unstocked acres simulate regeneration failure; acres shifted from unstocked acres simulate planting backlogged acres. Unstocked acres remain unstocked unless they are shifted into the productive timberland base. Unstocked acres are shifted into timberland based on the regeneration distribution by stocking level for MI1. Once in MI1 acres, unstocked acres are treated exactly like MI1 acres.

Related card type(s):

GRU 20—Regeneration cost of unstocked acres.

GRU 21—Proportion of unstocked acres restocked.

GRU 22—Proportion of cut acres left unstocked.

GRU 23—Proportion of MI1 acres regenerated in each stocking level 1 to 3.

Program use: Read in BRUSCN; summed in ACUSCN's subroutine SUM; used in TRIM's subroutine SHIFT.

BRU Card Type 2, Donor Acres

Item(s): Donor acres for Donors 1 and 2.
Real array by age class and donor: DONBRU.

Default: No donor acres.

Limits: Nonnegative and less than 1 billion per age class, up to 8 cards possible.

Description: Initial pool of stocked acres that are outside the timberland base. The donor acres are designed to provide a pool of acres that can be shifted into the timberland base or that can represent a pool of acres that receive acres from the timberland base. Increases and decreases in donor acres may simulate sale or purchase, respectively, of timberland. Donor 2 acres may grow older, stay in a fixed age-class distribution, or be grown exactly as the timberland inventory age class distribution, depending on the ACU donor growth option specification. Donor 1 acres only grow older. Donor acres assume existing volumes per acre when shifted.

Related card type(s):

GRU 25—Stocking level of donor acres.

GRU 26—Proportion of donor acres to shift to timberland base.

GRU 27—Proportion of timberland acres to shift to donors.

GRU 29—Donor exogenous volume proportions.

ACU A4—Donor 2 growth method.

Program use: Read in BRUSCN; summed in ACUSCN's subroutine SUM, reduced in program TRIM's subroutine SHIFT.

BRU Card Type 3, Regular Acres

Item(s): Regular acres and volumes per acre by stocking level. Real arrays by age class and management intensity: ACBRU, VPABRU.

Default: No acres or volume per acre for a given age class; however, there must be some initial inventory present.

Limits: Nonnegative, normalities with very high values (stocking proportions of standard volume per acre) flagged; maximum normality may be imposed, values greater than 0.0 and less than 1 billion per age class, up to 160 cards may be present (18 age classes by five management intensities).

Description: Initial acres in timberland base with associated volumes per acre by age class, stocking level, and management intensity.

Related card type(s):

GRU 23—Stocking level midpoints and regeneration distribution for MI1.

GRU 24—Stocking level entry proportion for MI1 and midpoints for MI2 to 5.

GRU 33—Standard net volumes per acre.

ACU 02—Time information and normality limits.

Program use: Read in BRUSCN; summed in ACUSCN's subroutine SUM; used in TRIM's subroutines ALOCAT, SHIFT, GROW, EXOGEN, and AGGREG.

GRU Card Descriptions

GRU Card Type 00, GRU Name

Item(s): 15-character alpha name for GRU.
Simple character variable: GRUNAM.

Default: GRU identification code converted to character form.

Limits: 15 characters, only one card.

Description: GRU name is printed on any report at the GRU level.

Related card type(s): None except that the name should correspond to the meaning of the integer identifiers for the BRU's and particular GRU.

Program use: Read in GRUSCN, printed in subroutines INVREP, HARREP, REGREP, ECOREP, LANREP, and SUMREP called by subroutines REPORT and REPACU in program TRIM.

GRU Card Type 01, BRU's Belonging to GRU

Item(s): BRU identification codes and proportions of BRU use. Integer and real arrays by number of BRU's: BRUID and BRUPRO.

Default: None for identification code, 1.0 for proportion of use, at least one BRU identification code must be present.

Limits: 50 BRU's, 17 cards for 50 BRU pairs identification code and proportion, five-digit code for each BRU, use proportion greater than 0.0 and less than or equal to 1.0.

Description: If a BRU identification code is entered without an associated proportion of use, the proportion of use defaults to 1.0; if a BRU identification is followed by a proportion of use, that value is used. BRUSCN designates all values greater than 1 as identification codes and all values greater than 0.0 and less than or equal to 1.0 as proportions of use. Identification codes are converted to integer values by truncation. Proportions of use are multiplied by acres and volumes during assignment of BRU's to a GRU.

Related card type(s): None, except all cards in the corresponding BRU must have the same identification code.

Program use: Read in GRUSCN; used in ACUSCN's subroutine SUM.

GRU Card Type 02, GRU Site and Species

Item(s): Site class index, original species and conversion species for GRU; simple integer variables: SITE, ORGSP, CVSP.

Default: None for SITE and ORGSP; no conversion for CVSP (CVSP = 0). Site and original species must be specified.

Limits: Site indices 1 to 3, ORGSP and CVSP species codes 1 to 9, only 1 card type 02 for each GRU.

Description: Site indices 1 to 3 and species codes 1 to 9 correspond to the report labels on card types A7 and A8 in the ACU file. Conversion species missing or 0 means no conversion will occur. Conversion can only occur from MI1 to MI2.

Related card type(s):

ACU A7—ACU site names.

ACU A8—ACU species names and report groups.

Program use: Read in GRUSCN; used in TRIM's subroutines CNVERS, INVREP, HARREP, REGREP, ECOREP, and LANREP.

GRU Card Type 03, GRU Options

Item(s): Rational expectation flag; diagnostic report flag and first and last periods for printing diagnostic reports.
Simple integer variables; PNWRUN, DUMP, IFDUMP, LSDUMP.

Default: All 0.

Limits: PNWRUN = 0 or 1; DUMP = 0 or 1; IFDUMP 0 to MAXSIM (17); LSDUMP 0 to MAXSIM; only one card type 03 for each GRU.

Description: For management-intensity shifts based on rational expectation, PNWRUN is 1; otherwise PNWRUN is omitted or is 0. For printing diagnostic reports, DUMP is 1; otherwise DUMP is omitted or is 0. Note that DUMP produces voluminous output for checking; it therefore should be used for short simulations and testing of small data sets. If all costs and revenue cards are filled and PNWRUN is not selected, a complete financial accounting is still provided by the program if the economic report is selected.

Related card type(s):

GRU cards 10-19—Must be appropriately supplied for the PNW simulations, PNWRUN = 1.

GRU 09-Rotation age.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT.

GRU Card Type 04, Planting Stock Indicator

Item(s): Planting stock indicator for either regular or genetic stock: simple integer array; PLANT(mi).

Default: Regular stock for all MI's.

Limits: Only one card 04; with a single entry, blank or 0, for each MI.

Description: The entry is used to indicate either replanting in regular (blank) or genetic (enter 0) stock by management intensity. The indicator is used in the financial valuations and report sections of the program.

Related card type(s):

GRU 19—Regeneration cost per cut acre for MI and period.

GRU all card 30's—That relate to the use of genetic or regular stock.

ACU cards A5 and A6—Treatment and management-intensity names.

Program use: Read in GRUSCN; used in TRIM's subroutines SHIFT and CNVERS.

GRU Card Type 05, Precommercial Thinning Age Class for Each MI, 1 to 5

Item(s): Precommercial thinning age class for each management intensity; zero or blank indicates no PCT for the appropriate MI; integer array by MI; PCTAGE(mi).

Default: No precommercial thinning for all MI's

Limits: Only one card, nonnegative entries.

Description: The age indicated for each MI is used in the soil expectation calculations. If PCT is not desired but some other cost is incurred during the duration of the stand, then this card can be used to reflect the occurrence of that treatment.

Related card type(s):

GRU 18—Precommercial thinning cost per acre for period.

ACU cards A5 and A6—Treatment and management-intensity name.

Program use: Read in GRUSCN; used in TRIM's subroutines PNW, GROW, SHIFT, and LANREP.

GRU Card Type 06, Fertilization Age Class for Each MI, 1 to 5, and Applications 1 and 2

Item(s): Fertilization age class by management intensity; interger array by MI and application; FTAGES (mi,1); FTAGES (mi,2).

Default: No fertilization for all MI's.

Limits: Two application ages at most for each MI. Up to five cards may be present.

Description: The age classes entered by each MI indicate the age at which fertilization will occur. The age is used in the soil expectation calculations and to report the treatments and financial sections. For the MI's present, fertilization will occur up to two times. The following provides an example showing two fertilzation ages for MI3 at ages 2 and 4 and one fertilization for MI4 at age 3; no fertilization occurs for MI's 1, 2, and 5:

Card	MI	Age 1	Age 2
06	3	2	4
06	4	3	

Related card type(s):

GRU 17—Fertilization cost per acre for period.

GRU all card 30's—To reflect fertilization treatment for appropriate MI.

ACU cards A5 and A6—Treatment and management-intensity names.

Program use: Read in GRUSCN; used in TRIM's subroutines PNW, GROW, SHIFT, and LANREP.

GRU Card Type 07, Age Limits for Shifting

Item(s): Oldest age class for shifts to occur among MI's; integer array by MI-from and MI-to; HISHIF (mi-from, mi-to).

Default: Shifting at time of regeneration only.

Limits: Pairs must be presented in ascending order. Up to 10 card type 07's permitted.

Description: Shifting into higher management classes usually occurs at regeneration. The option presented here allows for shifting acres from lower to higher MI's as long as there has been no exclusive treatment that would make this unreasonable. For example, acres held in MI1 may have no treatment associated with them, and acres in MI2 may have a commercial thinning age class 4. The associated yield tables and thinning tables would reflect these actions. This card allows the shifting limits to be set such that acres could be shifted from MI1 to MI2 up to the age class before the thinning occurs. In this example, the HISHIF value would be set at 3 for a transfer of acres from MI1 to MI2. This transfer limit also plays a part in the soil expectation calculations in that if the analysis shows that it is economical to shift acres from MI1 to MI2, then as long as the limit had not been exceeded, shifting would occur. The following represents the range of possible entries with "X" representing the age class before the treatment occurs:

Card	MIfrom	MIto	HISHIF
07	1	2	X
07	1	3	X
07	1	4	X
07	1	5	X
07	2	3	X
07	2	4	X
07	2	5	X
07	3	4	X
07	3	5	X
07	4	5	X

Related card type(s):

GRU 33—Standard net volume per acre for MI and age class.

GRU 34—Thinning volume per acre for MI and age class.

All GRU and ACU cards connected with MI naming and values or volumes attributed to each MI along with all cards indicating the timing of any treatment.

Program use: Read in GRUSCN; used in TRIM's subroutines SHIFT, CNVERS, and PNW.

GRU Card Type 08, Minimum Harvest Age Class for Each MI, 1 to 5

Item(s): Minimum harvest age class for each MI; integer array by MI; MINHAR(mi).

Default: Minimum harvest age class for each MI set to 0.

Limits: Only one card with a maximum of five nonnegative entries.

Description: MINHAR(mi) is used to set the minimum age class that can be harvested from each MI. The age is also used when calculating the volume available for harvest. No volume below the minimum age class is included in the volume available for harvest in any time period.

Related card type(s):

GRU 33—Standard net volume per acre for MI and age class.

GRU 38—Preferred harvest proportion for age class.

Program use: Read in GRUSCN subroutine GRUSCH; MINHAR is used in TRIM's subroutines ALOCAT and AGGREG.

GRU Card Type 09, Rotation Age for Each MI, 1 to 5 (age in years)

Item(s): Rotation age for each MI for financial calculations; integer array by MI; ROT(mi).

Default: Rotation age is set equal to 0 and no soil expectation calculations are possible.

Limits: Only one card may be present.

Description: The rotation age is used in the soil expectation calculations. The age presented is presumed to be the actual financial rotation age for the MI indicated. The age listed here is not used to set the actual age of harvest. The rotation age is used solely to calculate soil expectation values for each MI.

Related card type(s):

GRU 03—GRU Options (PNWRUN).

GRU cards 10-20—All financial cards.

GRU 33—Standard Net Volume per Acre for MI and Age Class.

Program use: Read in GRUSCN; used in TRIM's subroutine PNW.

GRU Card Type 10, Discount Rate for Period

Item(s): Discount rate for each period for financial calculations; real array by period; DISCO(pd).

Default: Discount rate set equal to 0 and no soil expectation calculations.

Limits: Up to four card 10's may be present. The rate is entered as a decimal.

Description: The discount rate is utilized in the PNWRUN option of the program and used for each MI. The calculation of the soil expectation value utilizes the current rotation's prices, costs, and volumes and the second rotation's prices, costs, and volumes, which are assumed to be perpetual. An example of the soil expectation calculation follows:

Period = 0; age class = 0;
Regeneration cost per acre = $100 present rotation
= $115 second rotation
PCT age class 1 cost per acre = $101 present rotation
= $109 second rotation
Annual cost per acre = $2
Rotation age = 80 years
Final harvest volume per acre = 18,020 cubic feet
Price per unit = $3.24 present rotation
= $3.39 second rotation
Periodic discount rate for all periods = 0.04

Soil expectation value is calculated as follows:

Present value of revenues:

$$2{,}653.17 = \frac{18{,}020(3.24)}{(1.04)^{80}} + \frac{\frac{18{,}020(3.39)}{(1.04)^{80}-1}}{(1.04)^{80}}$$

Present value of costs:

$$226.79 = \frac{2.00}{0.04} + 100 + \frac{101}{(1.04)^{10}} + \frac{115}{(1.04)^{80}-1}$$
$$+ \frac{115}{(1.04)^{80}-1} + \frac{\frac{109}{(1.04)^{10}}}{(1.04)^{80}-1}$$

SE = present value of revenues - present value of costs
2,426.39 = 2,653.18 - 226.79

Related card type(s):

GRU 03—GRU options (PNWRUN flag).

All GRU cards having to do with rotation age, age of treatment, associated costs and revenues, and appropriate volume yields by treatment.

Program use: Read in GRUSCN; used in TRIM's subroutine PNW.

GRU Card Type 11, Price per Unit for Period

Item(s): Price per unit of harvest for each period; real array by period; PRICE(pd).

Default: PRICE is set equal to 0.

Limits: Up to 4 card 11's may be present.

Description: The price values are used in the soil expectation calculations. The prices may be adjusted by period to reflect some real price trend. The prices must be based on the unit of measurement used in the yield tables. Remember, when using stumpage prices, to not include the harvest costs. When using log prices, harvest costs should be included.

Related card type(s):

GRU 03—GRU options.

GRU cards 10-20—All cards with financial information.

GRU cards 33 and 34—Standard net volume per acre for MI and age class and thinning volume per acre for MI and age class.

Program use: Read in GRUSCN; used in TRIM's subroutines ALOCAT, CNVERS, THIN, MORTAL, and PNW.

GRU Card Type 12, Annual Cost per Acre for Period

Item(s): Annual cost per acre for period in soil expectation calculations; real array by period; ANNCO(pd).

Default: ANNCO(pd) is set equal to 0.

Limits: Up to four card 12's may be present.

Description: The annual cost is used in the soil expectation calculations. It is designed to represent an annual, recurring cost. The value is amortized with the current period's discount rate in the soil expectation calculations only.

Related card type(s):

GRU 03—GRU options.

GRU 10—Discount rate for period.

Program use: Read in GRUSCN; used in TRIM's subroutines PNW.

GRU Card Type 13, Final Harvest Cost per Unit for Period

Item(s): Final harvest cost per unit of harvest for each period (variable cost); real array by period; HARUNT(pd).

Default: HARUNT(pd) is set equal to 0.

Limits: Up to four card 13's may be present.

Description: The final harvest cost per unit of harvest must be in the same units as the base yield tables. If you are calculating stumpage values, then HARUNT should be set equal to 0. Costs may be changed by period to represent increases or decreases in real costs over time. This cost is multiplied by all harvest volume and is used in the soil expectation calculations (assuming that log prices are used) and financial accounting methods.

Related card type(s):

GRU 03—GRU options.

GRU cards 10-20—Financial cards.

GRU cards 33-34—Standard net volume and thinning volume per acre by age class.

Program use: Read in GRUSCN; used in TRIM's subroutines ALOCAT and PNW.

GRU Card Type 14, Final Harvest Cost per Acre for Period

Item(s): Final harvest cost per acre for each period (fixed cost); real array by period; HARCO(pd).

Default: HARCO is set equal to 0.

Limits: Up to four card 14's may be present.

Description: The final harvest per acre is multiplied by the total number of acres harvested each period. The value should be used when log prices are used and not stumpage values. The costs are used in the soil expectation calculations.

Related card type(s):

GRU 03—GRU options.

GRU cards 10-20—Financial cards.

Program use: Read in GRUSCN; used in TRIM's subroutines ALOCAT and PNW.

GRU Card Type 15, Commercial Thinning Cost per Unit for Period

Item(s): Commercial thinning cost per unit for each period (variable cost); real array by period; CTUNIT(pd).

Default: CTUNIT is set equal to 0.

Limits: Up to four card 15's may be present.

Description: The commercial thinning cost per unit for each period is used in conjunction with the thinning volume table. The cost per unit is multiplied by the total volume harvested from the thinning table. These costs are used in the soil expectation calculations.

Related card type(s):

GRU 03—GRU options.

GRU cards 10-20—Financial cards.

GRU 34—Thinning volume per acre for MI and age class.

ACU A5—ACU treatment name.

Program use: Read in GRUSCN; used in TRIM's subroutines THIN and PNW.

GRU Card Type 16, Commercial Thinning Cost per Acre for Period

Item(s): Commercial thinning cost per acre for each period (fixed cost); real array by period; CTCO(pd).

Default: CTCO(pd) is set equal to 0.

Limits: Up to four card 16's may be present.

Description: The commercial thinning cost per acre is multiplied by the total number of acres thinned in each time period. These costs are used in the calculation of the soil expectation values.

Related card type(s):

GRU 03—GRU options.

GRU cards 10-20—Financial cards.

ACU A5—ACU treatment name.

Program use: Read in GRUSCN; used in TRIM's subroutines THIN and PNW.

GRU Card Type 17, Fertilization Cost per Acre for Period

Item(s): Fertilization cost per acre for each period (fixed cost); real array by period; FERTCO(pd).

Default: FERTCO(pd) is set equal to 0.

Limits: Up to four card 17's may be present.

Description: The fertilization cost per acre is applied to all acres fertilized in each period. It is used in conjunction with FTAGES (GRU 06). The costs are used in the soil expectation calculations.

Related card type(s):

GRU 03—GRU options.

GRU 06—Fertilization age class for each MI, 1 to 5, and applications 1 and 2.

GRU 33—Standard net volume per acre for MI and age class.

Program use: Read in GRUSCN; used in TRIM's subroutines GROW and PNW.

GRU Card Type 18, Precommercial Thinning Cost per Acre for Period

Item(s): Precommercial thinning cost per acre for each period (fixed cost); real array by period; PCTCO(pd).

Default: PCTCO is set equal to 0.

Limits: Up to four card 18's may be present.

Description: The precommercial thinning cost per acre is used in conjunction with PCTAGE (GRU 05) in the soil expectation calculations and is applied to all eligible acres by period. No revenue is attributed to the PCT section of the model; therefore, any other cost used in this card should not have any revenue associated with it that cannot be netted out of this entry.

Related card type(s):

GRU 03—GRU options.

GRU 05—Precommercial thinning age class for each MI, 1 to 5.

ACU A5—ACU treatment name.

Program use: Read in GRUSCN; used in TRIM's subroutines GROW and PNW.

GRU Card Type 19, Regeneration Cost per Cut Acre for MI and Period

Item(s): Regeneration cost per cutover acre for each MI and each period; real array by period and MI; REGCO(pd,mi).

Default: REGCO is set equal to 0.

Limits: Up to 20 card 19's may be present.

Description: The regeneration cost per acre by management intensity is the cost associated with an acre that has just been harvested. This cost is by MI to allow for different regeneration cost associated with site preparation and planting genetically improved stock, for example. This cost is used in the soil expectation calculations.

Related card type(s):

GRU 03—GRU options.

GRU cards 10-20—Financial cards.

ACU A5—ACU treatment name.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT, CNVERS, and PNW.

GRU Card Type 20, Regeneration Cost per Unstocked Acre for MI and Period

Item(s): Regeneration cost for each unstocked acre brought into the productive timberland base; real array by period and MI.

Default: UNSTCO is set equal to 0.

Limits: Up to 20 card 20's may be present.

Description: The regeneration cost per unstocked acre is multiplied by those acres that are brought into the timberland base each period from the unstocked category.

Related card type(s):

GRU 21—Proportion of unstocked acres restocked for period.

BRU 01—Unstocked acres.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT.

GRU Card Type 21, Proportion of Unstocked Acres Restocked for Period

Item(s): Proportion of unstocked acres to be restocked for each period; real array by period; UNSTRE(pd).

Default: UNSTRE is set equal to 0.

Limits: Up to four card 21's may be present.

Description: The proportion of unstocked acres to be restocked each period is multiplied by the total number of acres in the unstocked category for that period before any shifting takes place. These acres are regenerated into MI1 according to the regeneration distribution for SL 1, 2, and 3. These acres can subsequently move to a higher management intensity. Acres can intially enter the unstocked category from the INVEN file or may be moved there from harvested acres during the simulation.

Related card type(s):

GRU 22—Percent of cut acres to unstocked.

BRU 01—Unstocked acres.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT.

GRU Card Type 22, Proportion of Cut Acres to Unstocked for Period

Item(s): Proportion of cut acres to be shifted to the unstocked category for each period; real array by period between 0.0 and 1.0; CUTUNS(pd).

Default: CUTUNS(pd) is set equal to 0, and no acres are shifted to the unstocked category.

Limits: Up to four card 22's may be present.

Description: The proportion of acres per period that move to unstocked acres from harvested acres. The proportion indicated is applied across all MIs; that is, acres leaving the timberland base leave in proportion to the total acres harvested by MI.

Related card type(s):

GRU 21—Proportion of unstocked acres restocked for period.

Program use: Read in GRUSCN; used in TRIM's SHIFT.

GRU Card Type 23, Stocking Level Midpoint for MI1, Stocking Levels 1 to 3; Proportion of MI1 Acres Regenerated in Each Stocking Level, 1 to 3

Item(s): Stocking level (SL) midpoints for MI1; real number between 0.0 and 4.0; SLMID(sl); proportion of MI1 acres regenerated into stocking level 1; real number between 0.0 and 1.0, all three entries must sum to 1.0 however; SLDIST(sl).

Default: For SLMID(sl), SL1 = 1.0, SL 2 and 3 = 0.0; for SLDIST(sl), all acres will be regenerated into SL1.

Limits: Only one card 23 may be present.

Description: Stocking level midpoints allow for adjusting the normal volumes (GRU 33) by a percentage reduction or increase. As MI1 has three stocking levels, three entries are available. The normal volumes are multiplied by the percentages to adjust the actual volumes allocated to the three stocking levels. Even though the allocation takes place at the SL midpoint, the stands can still be grown using approach-to-normality (GRU 30, assuming that option is selected); therefore, stands may acquire more volume per acre in each stocking level than is actually indicated in the appropriate entry. The usual procedure to calculate these values is to multiply all volumes per acre of the initial inventory by the number of acres for each age class, and all volumes are summed to a total actual volume. The same acres are then multiplied by the appropriate age class entry in the yield table or standard volumes and summed to obtain total normal volume. Total actual volume is then divided by total normal volume. The quotient is the midpoint stocking level for the MI and stocking level. The stocking level distribution of acres regenerated in MI1, SL 1, 2, and 3 are indicated. The three entries must sum to 1.0. These entries indicate how cutover acres are distributed among the three stocking levels in MI1. These values are usually calculated by summing all acres for the last 30 to 50 years and dividing that value into the sum of acres by stocking level.

Related card type(s):

GRU 33—Standard net volume per acre for MI and age class.

GRU 24—Minimum stocking proportion to enter stocking levels 1 and 2.

Program use: Read in GRUSCN; SLMID is used in TRIM's subroutines SHIFT, GROW, and PNW.

GRU Card Type 24, Minimum Stocking Proportion to Enter Stocking Levels 1 and 2; Stocking Level Midpoint for Stocking Level 1 of MI 2 to 5 (MT 5 to 8)

Item(s): Minimum stocking proportion to enter stocking levels 1 and 2; real array by stocking levels 1 and 2 between 0.0 and 4.0; SLMIN: Stocking level midpoint for stocking level 1 of MI2 to MI5; integer between 0.0 and 4.0; SLMID.

Default: For SLMIN 2 and 3, they are set to 0.0: for SLMID 2 through 5, they are set to 1.0.

Limits: Only one card 24 may be present.

Description: The minimum stocking proportion to enter stocking levels 1 and 2 represent thresholds for volumes per acre. Once the threshold is surpassed, the acres are shifted from the lower stocking level to the next higher one. After an acre is grown under approach-to-normality, the new volume per acre is compared to the standard volume. If the proportion is higher than the minimum proportion, the acre is shifted to the higher stocking level. This only applies to MI1 because it is the only MI with more than one stocking level. MI's 2 through 5 have only one stocking level. The entries represent the proportion applied to the normal volumes (GRU 33) in order to establish the standard volumes per acre for each of the higher MI's. These values are also used in INVEN to reallocate acres of the initial inventory based on the given volumes per acre relative to the standard volume per acre as adjusted by these entries.

Related card type(s):

GRU 23—Stocking level midpoint for MI 1, stocking levels 1 to 3;

GRU 30—Growth type and approach-to-normality

GRU 33—Standard net volume per acre for MI and age class.

Program use: Read in GRUSCN; used in ACUSCN's subroutine SUM and program TRIM's subroutine GROW.

GRU Card Type 25, Stocking Level of Each Donor 1 and 2

Item(s): Stocking level for each donor category upon entry into the timberland base; integer array by donor; ODSTOC.

Default: All acres will be restocked in SL1.

Limits: Only one card 25 may be present.

Description: When acres are shifted to the timberland base from either of the donor categories, they must be placed in a prespecified stocking level. If stocking level 2 or 3 (SL2 or SL3) is specified, it applies only to MI1.

Related card type(s):

BRU 2—Donor acres for each donor 1 and 2, and age class.

GRU 23—Stocking level midpoint for MI1, stocking levels 1 to 3; proportion of MI1 acres regenerated in each stocking level 1 to 3.

GRU 24—Minimum proportion to enter stocking levels 1 and 2; stocking level midpoint for stocking level 1 of MI2 to 5.

GRU 26—Proportion of donor acres to shift to MI for period.

ACU A4—ACU shift specification.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT.

GRU Card Type 26, Proportion of Donor Acres to Shift to MI for Period

Item(s): The proportion of donor acres to shift to the receiving MI's for each period; real array by period, donor and MI; DONOR (pd,od,mito).

Default: Default is no donor shifting.

Limits: Up to 40 card 26's may be present.

Description: The proportion of acres shifted each period from each outside donor to each MI. The proportion of acres shifted is by period and is applied to the total number of acres in the donor each period. The stocking level of each donor is specified on GRU 25. The shifts are subscripted first by period, second by donor (1,2), and third by MI (1-5).

Related card type(s):

BRU 2 —Donor acres for each donor 1 and 2, and age class.

GRU 25 —Stocking level of each donor 1 and 2.

GRU 29 —Donor exogenous volume proportions.

ACU A4 —ACU shift specification.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT.

GRU Card Type 27, Proportion of MI Acres to Shift to Donor for Period

Item(s): Proportion of timberland MI acres to shift to each donor for each period; real array by period; values between 0.0 and 1.0; MIOUT(pd,mifr,od).

Default: No MI to donor shifting occurs.

Limits: Up to 40 card 27's may be present.

Description: The proportion indicated is used to determine how many acres in the designated MI are to be shifted from the total acres to the designated donor for the current period. Only acres in stocking level 1 shift out. The proportion is multiplied by the total acres in the MI and that amount is shifted to the donor. The acres, once shifted, assume the stocking level designated for the receiving donor. The proportions are first subscripted by period, second by the MI losing acres, and third by the donor that will be gaining acres.

Related card type(s):

GRU 25—Stocking level of each donor 1 and 2.

GRU 29—Donor exogenous volume proportions.

Program use: Read in GRUSCN; used in TRIM's SHIFT.

GRU Card Type 28, Preselected Proportion to Shift Among MI's for Period

Item(s): The proportion of each MI to be shifted to the other MI's for each period; real array by period, MI from, MI to; between 0.0 and 1.0; MISHIF(pd,mifr,mito).

Default: No preselected shifts will occur.

Limits: Up to 100 card 28's may be present.

Description: The proportions indicated are used to determine the amount of acres out of the total number of acres in the designated donating MI that will be shifted each period to the designated receiving MI. The proportions are subscripted first by the sending MI and then by the receiving MI. Shifts in both directions at the same time are possible. The proportion is applied to the total number of acres in each MI at the start of the period. In MI1, only acres in stocking level 1 are available to be shifted. If the soil expectation flag is set, these entries are ignored. Conversion is assumed to take place between MI1 and MI2.

Related card type(s):

GRU 07—Age limits for shifting.

Program use: Read in GRUSCN; used in ACUSCN and TRIM's subroutines SHIFT and CNVERS.

GRU Card Type 29, Exogenous Volume Proportion Recovered From Donor Acres for Period

Item(s): The proportion of volume from acres shifted to the donor category, which will be added to exogenous harvest; real array by period and donor; values between 0.0 and 1.0; DONCAP (pd,od).

Default: No exogenous volume will be recovered if shifting to a donor occurs.

Limits: Up to eight card 29's may be present.

Description: The proportion indicated is used to determine the amount of exogenous harvest volume from acres shifted from the timberland base to a donor category. The proportion is designed to represent a one-time harvest from acres shifted from the base and can be used to simulate no removal or total removal of the volume of the acres shifted.

Related card type(s):

GRU 27—Proportion of MI acres to shift to donor for period.

GRU 33—Standard net volume per acre for MI and age class.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT.

GRU Card Type 30, Growth Type and Approach-to-Normality

Item(s): Indicators for the type of growth for the GRU; GROTYP either 0 or 1; FULLAP integer; HALFAP integer; INTAP real; COEFAP real.

Default: GROTYP equals 0 and no approach-to-normality.

Limits: Only one card 30 may be present.

Description: GROTYP is the indicator of whether approach-to-normality (enter 1) will be used to determine growth from one period to the next or whether the growth will be determined from the yield tables (enter 0) only. If the yield table option is selected, then the yields indicated in GRU 33 will take the place of the yields indicated in the initial inventory after the first time period. If approach-to-normality is chosen, the yields indicated in the initial inventory are maintained but are grown relative to the yields indicated in GRU 33.

FULLAP indicates the last age class to receive the full increase in growth calculated in the approach-to-normality. The full increase in volume proportion obtained from the approach-to-normality function is used for all age classes up to and including this age class.

HALFAP indicates the last age class to receive one half of the increase in growth calculated in the approach-to-normality. One-half of the increase in volume proportion will be used for all age classes greater than FULLAP and less than or equal to HALFAP age class. No increase in volume proportion is used for those age classes greater than HALFAP.

INTAP is the intercept of the linear approach-to-normality function.

COEFAP is the slope coefficient of the linear approach-to-normality function. COEFAP is multiplied by the current volume proportion and then added to INTAP to equal volume proportion after growth. The following provides an example of the approach-to-normality concept:

normal volume = yield table volume (GRU 33) = 3000 cubic feet,

actual volume = INVEN file or regular volume = 1500 cubic feet,

$$\text{current volume proportion} = \frac{\text{actual volume}}{\text{normal volume}} = \frac{1500}{3000} = 0.50$$

where: INTAP = 0.11 and COEFAP = 0.90

Volume proportion = 0.11 + 0.9 * (current volume proportion) after growth,

$$0.56 = 0.11 + 0.9 * (0.5).$$

If the age class that the actual and normal volumes were obtained from is equal to or less than FULLAP, then the acres associated with that age class (which are currently 50-percent stocked) will be 56-percent stocked next time period. If the age class is greater than FULLAP and equal to or less than HALFAP, the acres associated with the age class will be 53-percent stocked next time period. If the age class is greater than HALFAP, then the acres will remain 50-percent stocked the next time period.

Related card type(s):

BRU 3—Regular acres and volumes per acre (at the GRU aggregation level).

GRU 33-Standard net volume per acre for MI and age class.

Program use: Read in GRUSCN; used in TRIM's subroutine GROW.

GRU Card Type 31, Mortality Salvage

Item(s): Indicator of desire to salvage mortality and the amount salvable; MORSAL either 0 (off) or 1 (on); MORPRP real between 0.0 and 1.0; MORVOL real.

Default: No mortality salvage is taken.

Limits: Only one card 31 may be present.

Description: MORSAL indicates whether mortality salvage is desirable. If the mortality salvage flag is activated (an entry of 1) then the amount of salvage volume available for each age class is found on GRU 35.

MORPRP indicates the proportion of the salvage volume indicated on GRU 35 that can be salvaged.

MORVOL indicates a minimum amount of volume that must be present before the salvage volume can be added to the harvest. If the salvable proportion of mortality volume multiplied by the mortality volume per acre is less than minimum salvable volume per acre, mortality salvage will not occur. If mortality salvage is selected, it is conducted across all MIs, and the volume calculated is an exogenous volume and is calculated before the actual harvest is taken.

Related card type(s):

GRU 35-Mortality volume per acre for MI and age class.

Program use: Read in GRUSCN; used in TRIM's subroutines EXOGEN and MORTAL.

GRU Card Type 32, Average Diameter for MI and Age Class

Item(s): Average diameter for each MI by age class; real array by age class and MI AVDIAM(ac,mi).

Default: No diameter reporting will occur.

Limits: Up to 20 card 32's may be present.

Description: The average diameter of all trees included in the specific MI and age class for each age class. AVDIAM should correspond to the base yield table utilization standard and is used for reporting purposes.

Related card type(s):

GRU 33—Standard net volume per acre for MI and age class.

ACU 03—Age class report groups.

Program use: Read in GRUSCN; used in TRIM's subroutines ALOCAT, SHIFT, GROW, and INVENT.

GRU Card Type 33, Standard Net Volume per Acre for MI and Age Class

Item(s): Standard net volume per acre for each MI and each age class; real array by age class and MI; VOLPA(ac,mi).

Default: No default.

Limits: Up to 20 card 33's may be present.

Description: The standard volume per acre in the base volume measure by age class and MI. These yields are the actual yields if no approach-to-normality is chosen or, if chosen, the yields provide the standard volumes for the approach-to-normality calculations. The standard volumes per acre are adjusted for each MI (and stocking level) by use of the parameters included on GRU 23 and 24 (stocking level midpoints).

Related card type(s): All cards indicated in the BRU and GRU file are related to the normal volume yield tables.

Program use: Read in GRUSCN; used in TRIM's subroutine SHIFT, GROW, CNVERS, and PNW.

GRU Card Type 34, Thinning Volume per Acre for MI and Age Class

Item(s): Thinning volumes for each MI and age class; real array by age class and MI; THINPA(ac,mi).

Default: No thinning occurs.

Limits: Up to 15 cards may be present.

Description: Thinning volume per acre in the base volume measure by age class and MI. If a thinning volume per acre is indicated for any MI, then that MI will have a thinning in the age class indicated by the placement of the thinning volume. In an age class where thinning occurs, VOLPA should equal total volume per acre before harvest. THINPA should equal the thinning volume that can be removed from VOLPA. THINPA is adjusted by the stocking level midpoint and the growth on harvest. No thinning can occur in SL2 and 3 of MI1.

Related card type(s):

GRU 15 and 16—Fixed and variable cost of thinning.

Program use: Read in GRUSCN; used in TRIM's subroutine GROW, THIN, and PNW.

GRU Card Type 35, Mortality Volume per Acre for MI and Age Class

Item(s): Mortality volume per acre for each MI and age class; real array by period; MORTPA(ac,mi).

Default: No mortality salvage.

Limits: Up to 20 card 35's may be present.

Description: The mortality volume per acre in the base utilization standard by age class and MI. The mortality volume is used in the mortality salvage option.

Related card type(s):

GRU 31—Mortality salvage.

Program use: Read in GRUSCN; used in TRIM's subroutine MORTAL.

GRU Card Type 36, Softwood Proportion of Volume per Acre for MI and Age Class

Item(s): The proportion of softwood volume per acre for each MI and age class; real array by age class and MI; 0.0 and 1.0; SOFTPA(ac,mi).

Default: SOFTPA is set equal to 1.0.

Limits: Up to 20 card 36's may be present.

Description: The softwood proportion of total volume by age class by MI. The proportion is multiplied by the volume per acre to determine the actual amount of softwood that can be removed by age class and MI. Totals are maintained for softwood, hardwood, and total volume and are applied depending on the harvest request (softwood, hardwood, or combined).

Related card type(s):

ACU A3—ACU harvest volume for period.

GRU 33—Standard net volume per acre for Mi and age class.

Program use: Read in GRUSCN: used in TRIM's subroutine ALOCAT, SHIFT, GROW, INVENT, AGGREG, CNVERS, THIN, and MORTAL.

GRU Card Type 37, Adjustment Factor for Growth on Harvest for MI and Age Class

Item(s): Growth adjustment factor for growth on available volume for harvest each MI and age class; real array by age class and MI; HARGRO(ac,mi).

Default: No growth on harvest is calculated.

Limits: Up to 20 card 37's may be present.

Description: The growth adjustment factor provides an option for including the growth on the available volume targeted to be harvested in each GRU for each period. Assume that the standard volumes per acre (GRU 33) are midperiod values, that trees are harvested within any age class on an oldest first basis, and that the trees within any age class are evenly distributed across the age class. The first year's harvest would be trees 99 years old (assuming age class 9 with a midpoint volume and age of 95), but a volume associated with age class 95 would be removed. A value is therefore entered that will adjust the volume per acre of the harvested acres upward to reflect growth for one-half of a period for the given age class. For the 10-year-period problem, the value entered is the ratio of the volume entered in the normal yield tables for trees aged 95, divided into the normal volume per acre for trees aged 100. For example, if the normal volumes indicated that the yield for age class 9 (aged 95) was 2,500 cubic feet per acre and the yield for age class 10 (age 105) was 3,500 cubic feet per acre, then the yield at age 100 would be about 3,000 cubic feet per acre. The adjustment factor for age class 9 would be 1.2, which will adjust 2,500 cubic feet per acre up to 3,000 cubic feet per acre. The growth adjustment calculated is applied only to acres that are being harvested, and the adjusted growth is not reported. These calculations must take place outside the model.

Related card type(s):

GRU 33—Standard net volume per acre for MI and age class.

ACU 02—Time information.

Program use: Read in GRUSCN; used in TRIM's subroutine ALOCAT, AGGREG, CNVERS, and THIN.

GRU Card Type 38, Preferred Harvest Proportion for Age Class

Item(s): The preferred harvest proportion for each age class to be harvested; real array by age class; all entry values must accumulate to 1.0; HVPROP(ac).

Default: HVPROP for age class 17 equals 1.0 (oldest first).

Limits: Up to four card 38's may be present.

Description: The proportion of harvest volume requested by each age class. If an oldest first priority is desired, enter 1.0 for age class 17. If a proportion is to be harvested from several age classes, enter that proportion for each age class. Proportions must total to 1.0. When volume is exhausted in the designated age classes, the program reverts to an oldest first harvest priority. If volume is not exhausted, it is removed relative to the amount of volume available in each class to the harvest proportion for that age class. The proportions must be entered in age classes equal to or greater than MINHAR and equal to or less than age class 17.

Related card type(s):

GRU 08—Minimum harvest ages.

Program use: Read in GRUSCN; used in TRIM's subroutine ALOCAT.

GRU Card Type 39, Volume Conversion Factor for Age Class (to convert from base volume unit to alternate volume unit)

Item(s): Volume conversion factors for each age class; real array by age class; CONFAC(ac).

Default: CONFAC is set equal to 1.0.

Limits: Up to four card 39's may be present.

Description: Age class conversion factors used to convert inventory and harvest volume to the alternate volume measure. CONFAC is used for report purposes only when the alternate volume measure harvest report is requested.

Related card type(s):

GRU 33—Standard net volume per acre for MI and age class.

ACU 04—Unit conversion specifications.

ACU 05—Report matrix.

Program use: Read in GRUSCN; used in subroutine ALOCAT, SHIFT, GROW, INVENT, CNVERS, THIN, and MORTAL.

ACU Card Descriptions

HEADER Card Type 01, Run Header

Item(s): Run header label RHEAD. A simple A60 character variable.

Default: None; must be present.

Limits: None; only one card.

Description: A title for all reports. RHEAD appears at the top of all report output.

Related card type(s): None.

Program use: Read in ACUSCN, and used in all report routines.

HEADER Card Type 02, Time Information

Item(s): Beginning year of simulation, STYEAR. Length of period and age class in years, LENPD. Ending period of analysis, MAXPD. Maximum proportion of stocking allowed, APLIM. Minimum proportion of stocking for warning, APMIN. Maximum proportion of stocking for warning, APMAX.

Default: STYEAR equals 0. LENPD equals 10. MAXPD equals 0. APLIM equals 100.0. APMIN equals 0. APMIN equals APLIM. One card must be present.

Limits: STYEAR and LENPD have none. MAXPD less than or equal to 17. APLIM less than or equal to 100.0. APMIN greater than or equal to 0.0. APMAX less than or equal to 100.0.

Description: STYEAR, the starting year is used to label the year interval on the reports. LENPD is the increment for the age class and period and is the overall time base for the model. MAXPD is the sole control over how many periods the simulation is run. APLIM is the maximum proportion of stocking allowed. Volume in excess of APLIM times standard volume per acre is shifted to older age classes. APMIN and APMAX are used to flag extreme values for stocking proportions so that some kind of external checking can be done. Very high stocking proportions are reduced gradually by the approach-to-normality equation, implying spurious growth.

Related card type(s):

GRU 33—Normal net volume per acre.

BRU 03—Regular inventory volume per acre.

Program use: Read in ACUSCN, and used in TRIM.

HEADER Card Type 03, Age Class Report Groups

Item(s): Age class report group indicator, ACGRP(ac). There are eight groups for the 18 age classes.

Default: None; the card must be present.

Limits: None; 18 cards must be present.

Description: There are 18 age classes (0-17) that must be combined into no more than eight (1-8) report groups. They may be grouped in any fashion that the user desires. Each age class is listed and the appropriate group (1-8) is listed next to it.

Related card type(s): None.

Program use: Read in ACUSCN, and used in all report routines.

HEADER Card Type 04, Unit Conversion Specifications

Item(s): The alternate volume measure label, ALTUNT. The minimum diameter for conversion, DIAMIN.

Default: No conversion reports.

Limits: ALTUNT must be an A15 character. DIAMIN must be nonnegative and less than 100.0

Description: ALTUNT is the alternate volume measure label and is used on all reports when the alternate base unit is requested. DIAMIN is the minimum diameter for which volume conversion is done. When the volume is converted from the base to the alternate base, only the age classes where the diameter is greater than or equal DIAMIN are converted.

Related card type(s):

ACU—05 Report matrix.

Program use: Read in ACUSCN, and used in all report routines.

HEADER Card Type 05, Report Matrix

Item(s): REPMAT is a matrix of reports requested. It is subscripted by the five levels and the six types.

Default: Only ACU total report for inventory and harvest.

Limits: Nonnegative and less than or equal to 1.

Description: There are five levels of reports; (1) GRU detail, (2) ACU detail, (3) ACU summary, (4) ACU subgroup summary, and (5) ACU totals summary. The first two levels (1,2) are detailed reports printed every period. Levels three through five are summary reports that report all periods in one report. Detail reports provide the age class report groups and summary reports only summarized period values. There are six types of reports: inventory, harvest, alternative volume measure for inventory and harvest, regeneration and treatment, economic, and land shift. To request a report enter a 1 in the appropriate level and type a blank or 0 to omit a report. Columns 8-20 are reserved for comments if needed.

Related card type(s):

ACU—04 Alternative volume measure label and diameter minimum.

ACU—06 Subgroups lists.

GRU—39 Volume conversion factors.

Program use: Read in ACUSCN, and used in all report routines.

HEADER Card Type 06, ACU Subgroups

Item(s): SUBGR is a list of ACU's that are to be combined into a collective report. There are a maximum of 12 ACU subgroups.

Default: No subgroup reports.

Limits: ACU numbers that are in the current run. ACU numbers are between 1 and 50, and any ACU requested that is not in the run is flagged and omitted. A maximum of four cards can be used.

Description: ACU subgroups are unique groups of ACU's from which users would like summary reports. ACU subgroups are level four of the report matrix. There are three 20-column fields per card for input of subgroups. The ACU numbers can be entered separated by commas or, if the numbers are in a series, the first and last number separated by a dash can be entered; for example:

06	1,2,5,8,13	2-7	3,10
06	1-5,8-13	3,9	10-13

Related card type(s):

ACU—05 Report matrix

Program use: Read in ACUSCN, and used in all report routines.

ACU Card Type A1, ACU Name

Item(s): ACUNAM is the A15 character name associated with the ACU identification number.

Default: None.

Limits: Card must be present.

Description: ACUNAM is the character label printed with all ACU reports and is only used for identification.

Related card type(s): None.

Program use: Read in ACUSCN, and used in all ACU report routines.

ACU Card Type A2, GRU Membership List

Item(s): GRUID is a list of up to 50 GRU identification numbers to be combined into an allowable cut unit.

Default: None; at least one GRU must be present.

Limits: GRU's in the list must be present in the GRU RAF for the run.

Description: GRUID is the list of GRU's to be included in the allowable cut unit; these GRU's are maintained as individual inventories in the model. The ACU harvest is allocated to GRU's proportional to the available volume in the GRU. Available volume is computed by summing volume in age classes from MINHAR to the maximum. Available volume for each GRU is added to the total available volume for the ACU.

Related card type(s): GRU cards and appropriate identifier.

Program use: Read in ACUSCN; used throughout TRIM.

ACU Card Type A3, ACU Harvest Request

Item(s): HARTYP is the fiber type flag for the request. Fiber type entries are 1=softwood, 2=hardwood, and 3=combined. HRVACU is the by-period harvest volume request for this ACU. The volume is removed proportional to the volume available in the GRU's and according to the fiber type request.

Default: None; at least one harvest request is required.

Limits: Nonnegative, and less than or equal to 1.0E+12.

Description: HARTYP is used to specify the type of fiber used to fill the harvest request. If softwood or hardwood fiber is chosen, the other type of fiber is also cut and reported; if combined fiber type is chosen, both softwood and hardwood fiber is used to fill the harvest request. HRVACU is the volume request in the base volume measure. This request is by period and is allocated proportional to available volume in each GRU.

Related card type(s):

GRU 33—Net volume per acre.

GRU 36—Softwood proportion.

Program use: Read in ACUSCN; used in TRIM's subroutine PROPRT.

ACU Card Type A4, ACU Donor Shift Specification

Item(s): DONTOP is the shift method flag for Donor 2 acres only. Entries are: 1=normal method (grow older), 2=frozen in initial distribution, and 3=pool of acres which move in relative to existing acre base.

Default: Normal method, DONTOP=1.

Limits: Nonnegative, and less than or equal to 3.

Description: DONTOP allows three different types of acre movement into the land base from acres in donor 2 category only. Option one is the normal method where the initial acres grow older each period. Option two freezes the acres in the initial distribution; this can be used to shift specific-aged acres in at any time. Option three considers the donor acres as a pool of acres that has the same acreage distribution as the target MI.

Related card type(s):

BRU 2—Donor acres.

GRU 25—Donor stocking level.

GRU 26—Donor shift proportion.

Program use: Read in ACUSCN, used in TRIM's subroutine SHIFT.

ACU Card Type A5, ACU Treatment Labels

Item(s): TRNAME is an array of seven A15 character labels. The seven labels represent the cultural treatments for the ACU.

Default: None; there must be seven card A5's present.

Limits: None; A15 character.

Description: TRNAME is the label associated with the seven cultural treatments. Present usage is, 1=REGULAR STOCK, 2=GENETIC STOCK, 3=CONVERSION, 4=PRECOMM THIN, 5=FERTILIZATION, 6=COMM THIN, and 7=FINAL HARVEST. These labels are used to describe the treatments in the reports and should be right justified in the data fields.

Related card type(s): None.

Program use: Read in ACUSCN; used in all report routines.

ACU Card Type A6, ACU Management Intensity Labels

Item(s): MINAME is an A15 character label indexed from 1 to 5 and represents the management intensities for the ACU.

Default: None; there must be five card A6's present.

Limits: None; A15 character.

Description: MINAME is the label associated with the five management intensities. These labels are used to describe each MI in the reports and should be right justified in the data fields.

Related card type(s): All cards associated with MI's.

Program use: Read in ACUSCN, used in all reporting routines.

ACU Card Type A7, ACU Site Labels

Item(s): SITNAM is an array of three A15 character labels and represents the site group for the ACU.

Default: None; there must be three card A7's present.

Limits: None; A15 character.

Description: SITNAM is the label associated with the three site groups. These labels are used to describe each site group in the reports and should be right justified in the data fields.

Related card type(s): Related site cards.

Program use: Read in ACUSCN, used in all reporting routines.

ACU Card Type A8, ACU Species Labels and Fiber Type Indicator

Item(s): SPNAME is an array of nine A15 character labels and represents the species groups for the ACU. SPGRP is the fiber type indicator; it must be either 1 or 2.

Default: None; there must be one card A8 present.

Limits: None; A15 character.

Description: SPNAME is the label associated with the nine species groups. These labels are used to describe each species group in the reports. The fiber type indicator, 1 or 2, is used to indicate the general fiber type grouping for each species group.

Related card type(s): None.

Program use: Read in ACUSCN, used in all reporting routines.

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Metric Equivalents

1 hectare = 2.47 acres
1 cubic meter = 35.3 cubic feet

Appendix A
Synopsis of BRUSCN

The synopsis of BRUSCN is designed to provide the logical flow of the program. Indention reflects logical routine divisions.

Initialization for run.

Set creation date and time.

Zero BRU count and record count.

For each BRU:

1. Initialization for a BRU.

   Zero counts of active (data) and comment records.

   Zero count by card type.

   Zero acres and volumes per acre.

2. Read in character form and print input for a BRU.

   Subroutine CHECK controls paging.

   Comments at the beginning are printed immediately.

   Comments between active records are stored temporarily and then printed.

   Active cards are printed and stored.

3. Check and record BRU identification code.

   Search for illegal characters in code.

   Transform good character sets into numeric form for BRU list.

   Set indicator value for bad character sets and write message.

4. For each active card:

   a. Subroutine SET provides error count and record identification for errors.

   b. Check card type, MI, and age class.

      Transform character sets into numeric form.

      Write message if illegal characters encountered.

c. Check data fields.

   Transform character sets into numeric form.

   For blank fields, set missing values.

   For illegal characters or illegal character order, set special indicator value, locate column(s) of illegal characters, and write message.

d. Transfer data to variables and check limits.

   Screen illegal MI, age class, or MI-age class combinations and write message. Screen illegal data values and write message. For good MI, age class, or MI-age class combinations, put data in acres and volumes per acre variables.

5. Compute MI1 totals and average volumes per acre.

6. Write BRU record on BRURAF.

7. Print BRU report.

   Subroutine BRUREP computes totals over age classes, changes volumes from cubic feet to thousand cubic feet and writes nonzero values in tables, omitting sections that are all zero.

   Sort and write BRU list on BRURAF.

   Subroutine SHELL sorts BRU list into ascending order of BRU identifying codes, keeping the BRU error count and BRURAF location with the associated identifying code. Illegal BRU identifying codes sort to the end of the list.

   Write key record on BRURAF.

   Print sorted BRU list.

   Subroutine PRNLST prints the BRU list with associated BRURAF location and flags nonzero error counts.

Appendix B
Synopsis of GRUSCN

The synopsis of GRUSCN is designed to provide the logical flow of the program. Indention reflects logical routine divisions.

Initialization for run.

Set creation date and time.

Zero GRU count and record count.

For each GRU:

1. Initialization for a GRU.

   Zero counts of active (data) and comment records.

   Zero count by card type.

   Subroutine INIT sets variables to their default values.

2. Read in character form and print input for a GRU.

   Subroutine CHECK controls paging.

   Comments at the beginning are printed immediately.

   Comments among active records are stored temporarily and then printed.

   Active cards are printed and stored.

3. Check and record GRU identification code.

   Search for illegal characters in code.

   Transform good character sets into numeric form for GRU list.

   Set indicator value for bad character sets and write message.

4. For each active card:

   a. Subroutine SET provides error count and record identification for errors.

   b. Check card type, MI, and age class or period.

      Transform character sets into numeric form.

      Write message if illegal characters encountered.

c. Check data fields.

Transform character sets into numeric form.

For blank fields, set missing values.

For illegal characters or illegal character order, set special indicator value, locate column(s) of illegal characters, and write message.

d. Transfer data to variables and check limits.

Subroutine SINGLE handles one-dimensional arrays, subroutine DOUBLE handles two-dimensional arrays, and subroutine TRIPLE handles three-dimensional arrays for screening. Formal parameters provide array dimensions, array name, and lower and upper limits to these subroutines.

Screen illegal MI, age class, or period, or combination of MI-age class or MI-period and write message.

Screen illegal data values and write message.

For good MI, age class or period, or combination of MI-age class or MI-period, put data in variables.

5. Create GRU name if needed.

6. Apply fill values to arrays, substituting the value stored in the -1 position for age class or period for any missing values. Subroutine FILONE handles one-dimensional arrays, FILTWO handles two-dimensional arrays, and FILTHR handles three-dimensional arrays. If the -1 position has not been set, use the appropriate default value as the fill value.

7. Cross-check related data values.

Write message if total proportions shifted from MI acres or donor acres exceeds 1, if mortality salvage is requested when no mortality volumes per acre are provided, if more than three commercial thinnings are specified, if the preferred harvest proportions sum to more than 1, or if required card types are missing.

Report optional card types that are missing, indicating use of default values.

8. Print GRU report.

   Subroutine GRUREP writes a complete report for the GRU, including all default values invoked. Sample values for the approach-to-normality equation are printed.

   Blanks are printed for zero values.

9. Write GRU record on GRURAF.

   Sort and write GRU list on GRURAF.

   Subroutine SHELL sorts GRU list into ascending order of GRU identifying codes, keeping the GRU error count and GRURAF location with the associated identifying code. Illegal GRU identifying codes sort to the end of the list.

Write key record on GRURAF.

Print sorted GRU list.

Subroutine PRNLST prints the GRU list with associated GRURAF location and flags nonzero error counts.

Appendix C
Synopsis of ACUSCN

The synopsis of ACUSCN is designed to provide the logical flow of the program. Indention reflects logical routine divisions.

Initialization for run.

Set creation date and time.

Zero ACU count and record count.

Initialization for general ACU data.

Zero counts of active (data) and comment records.

Set general ACU data variables to default values.

Read in character form and print general ACU input.

Subroutine CHECK controls paging.

Comments at the beginning are printed immediately.

Comments between active records are stored temporarily and then printed.

Active cards are printed and stored.

Process general ACU cards.

The general ACU cards have very different formats, so each card type is handled separately. Illegal characters, illegal values, and missing required card types cause error messages.

Subroutine EXPAND converts 20 character lists of ACU's to numeric representations.

Print general ACU report.

Subroutine GENREP reports the general ACU data.

Subroutine ACULOP processes data for each individual ACU:

1. Subroutine SET provides error count and record identification for errors.

2. Initialization for a ACU.

    Zero counts of active and comment records.

    Zero counts by card type.

    Set individual ACU data variables to their default values.

3. Read in character form and print input for an ACU.

   Subroutine CHECK controls paging.

   Comments between active records are stored temporarily and then printed.

   Active cards are printed and stored.

4. Check ACU identification code and card type.

   Transform character sets into numeric code and card type.

   Write message if illegal characters are encountered.

5. For each active ACU card:

6. Apply fill values to harvest request, using FILONE to substitute the value stored in the -1 position for age class for any missing values.

7. Cross-check related data values.

   Missing required card types causes error messages.

8. Print ACU report.

   Subroutine ACUREP reports the individual ACU data.

9. Subroutine SUM processes each GRU belonging to the ACU and subroutine TREACU records the ACU tree information.

   a. For the first ACU, the BRU list is read from BRURAF and the GRU list from GRURAF.

   b. Set GRU sum to zero.

   c. Locate GRU using subroutine BINSRC and read GRU data.

   d. For each BRU belonging to the GRU:

      Locate BRU using subroutine BINSRC and read BRU data.

      Flag normalities outside expected limits.

      Add BRU date to GRU sum, making stocking level shifts according to GRU limits.

      Subroutine TREBRU records the BRU tree information.

    e. Redistribute summed GRU volumes to improve normality values, if requested.

    f. Subroutine TREGRU records GRU tree information.

    g. Write GRU record on BIGRAF, which includes GRU summed data.

    h. Subroutine GRUCMB reports GRU summed data, changing volumes from cubic feet to thousand cubic feet. Blanks are printed for zeroes.

10. Write ACU record on ACURAF.

    Check for presence of ACU subgroup members.

    Write key record on BIGRAF.

    Subroutine TRELST prints tree report and lists of BRU's and GRU's with their proportions of use.

Appendix D

Synopsis of TRIM

The synopsis of TRIM is designed to provide the logical flow of the program. Indention reflects logical routine divisions.

```
Initialization for run

Set date and time and write titles on output units.

Subroutine RUNINT blanks character arrays, sets various maximum values and page limits, reads the key record from BIGRAF, and writes the key record on CURRAF.

For each period:

   Compute and display year.

   For each ACU:

      Subroutine ACUINT sets up the ACU information.

   The ACU record is read from BIGRAF.

   For period 0, summary variables in common SUBSUM are zeroed; otherwise, CURRAF information for the ACU are read.

   ACU totals in common ACUDET are zeroed.

Display ACU number and name.

For each GRU in the ACU:

   Subroutine GRUINT sets up the ACU information.

   The GRU record is read from BIGRAF.

   Acres and volumes per acre for regeneration use are zeroed. Commercial thinning and harvest volumes are zeroed.

   For period 0, GRU values in common GRUDET are zeroed and net values for MI's are set; otherwise, GRU values are read from CURRAF.

   Subroutine ALOCAT assigns the harvest volume for last period to MI's and age classes, computes GRU harvest summary variables in common GRUDET, and adds GRU values to all ACU summary variables in common ACUDET. (Note: Harvest volume is zero for period zero.)

   If period is greater than zero, subroutine REPORT writes GRU detail reports, using information in common GRUDET, for last period.
```

Subroutine SHIFT zeroes all GRU summary variables in common GRUDET, regenerates cut and previously unstocked acres, shifts acres and volumes to and from donors and among MI's, and stores acres and volumes before growth. Conversion harvest volume from acres shifted to donors is computed by SHIFT. Subroutine PNW is called by SHIFT for the rational expectation option.

Subroutine INVENT sums inventory variables in common GRUDET.

Subroutine GROW records acres that are precommercially thinned or fertilized, projects volumes per acre and total volumes after growth, moves acres to the next age class, computes growth as the difference between volumes before and after growth, stores growth in common GRUDET, and shifts acres to correct stocking levels.

Subroutine EXOGEN calls subroutines CNVERS to compute harvest volume from converted acres and add it to conversion harvest volume, THIN to compute commercial thinning volume, and MORTAL to compute mortality salvage volume. EXOGEN sums these volumes to compute the total exogenous harvest for the GRU.

Subroutine AGGREG writes GRU values on CURRAF, computes volume available for harvest for the GRU, adds it to ACU total volume available, and adds the exogenous harvest for the GRU to the ACU total exogenous harvest.

Subroutine PROPRT uses the ACU and GRU available volumes, exogenous harvest volumes, and harvest request to assign harvest values to each GRU and calls subroutine GRUHAR to report the results. PROPRT calls subroutines REPACU to write the ACU detail reports for last period and SUMPD to store last period's summary variables in common SUBSUM. For the last period of the simulation, PROPRT zeroes the ACU summary variables in common ACUDET, calls subroutines GRULAS, ALOCAT, and REPORT to allocate the final period's harvest and write the final period's GRU detail report. PROPRT again calls subroutines REPACU to write the final period's ACU detail reports and SUMPD to store the final period's summary variables in common SUBSUM.

For each ACU, subroutine FINAL reads ACU summary variables in common SUBSUM from CURRAF, calls subroutine SUBREP to write the ACU summary report, and adds the ACU summary variables to the grand total variables. When all ACU's have been processed, FINAL calls subroutine SUBREP to write the grand total summary report. For each ACU subgroup, FINAL recalls ACU summary data for all ACU's belonging to the subgroup, forms the subgroup totals, and calls subroutine SUBREP to write the subgroup summary reports.

Subroutine ALOCAT

The first attempt to assign the harvest volume from the previous period to age classes uses the preferred harvest proportion. If the harvest volume is not exhausted, the second attempt allocates additional volume above the preferred proportion starting with oldest age class.

If the harvest volume is still not exhausted when all available volume has been assigned, the available amount is harvested and a warning message is written to output file CALLS.

Harvest volume in an age class is distributed to all MI's in equal proportions.

Final harvest is summed by fiber type and age class report group in GRU harvest summary variables in common GRUDET.

MI1 total acres and volumes are summed from MI1 stocking levels 1 to 3, and MI1 average volume per acre is computed.

Acres in all MI's are checked. Negative values and very small positive values from 1.0E-8 to 1.0E-20 are written in a warning message to output file CALLS and reset to zero; positive values less than 1.0E-20 are considered rounding errors and are reset to zero with no warning message. The volumes per acre and volumes corresponding to the acres reset are also set to zero.

Total and average GRU harvest summary variables in common GRUDET are computed.

GRU summary variables in common GRUDET are added to ACU summary variables in common ACUDET.

Subroutine SHIFT

Unstocked acres and harvested acres for the previous period are stored.

GRU summary variables in common GRUDET are zeroed.

Simple regeneration places cut acres that will be restocked into the MI's from which they were cut.

Cut acres that will remain unstocked are put into the newly unstocked categories by MI.

Previously unstocked acres that will be regenerated are assigned to MI1 for GRU's without conversion or to MI2 for GRU's with conversion selected.

Acres regenerated into MI1 are assigned to stocking levels according to the requested distribution for both cut acres and previously unstocked acres.

Regular acre totals and volumes per acre are computed.

Regular acres before shifting are stored.

Donor 2 acres are redistributed according to the proportions by age class of regular acres.

Donor acres before shifting are stored.

Acres are shifted to and from donors from and to the timberland base.

> The number of acres shifted is the proportion to shift this period times the acres before shifting in each age class belonging to the donor or the MI from which shifting originates.
>
> Volume from acres shifted to donors is captured as conversion volume, a component of exogenous harvest volume.
>
> Acres moved from MI1 to donors are taken from stocking levels according to their proportions in the inventory.
>
> Acres moved to MI1 from donors are assigned to the stocking level specified for the donor.
>
> If an age class for a management type has no acres before shifting, the volume per acre is computed as the standard volume per acre multiplied by the stocking level midpoint for that management type; otherwise, the volume per acre for the existing acres is used.
>
> For the rational expectation option of MI shifts:
>
> > Subroutine PNW is called to compute soil expectation values for each MI and all age classes up to the highest age for which shifting is permitted.
> >
> > For each age class, eligible acres and their volumes in each MI are shifted to the MI with the highest soil expectation value, subject to the age class limitations specified. For GRU's with conversion selected, shifts from MI1 are not permitted in this subroutine.
>
> For preselected MI shifts:
>
> > For each pair of MI's and for each age class, eligible acres and their volumes are shifted between the two MI's, subject to the age class limitations specified. For GRU's with conversion specified, shifts to or from MI1 are not permitted in this subroutine.
> >
> > The number of acres shifted is the proportion shifted this period times the acres before shifting in each age class belonging to the MI from which shifting originates.

MI 1 total acres and volumes and average volumes per acre are recomputed from MI 1 stocking levels 1 to 3.

Acres in all MI's are checked. Negative values cause a catastrophic error that stops the program; very small positive values from 1.0E-8 to 1.0E-20 are written in a warning message to output file CALLS and are reset to zero; values smaller than 1.0E-20 are considered rounding error and are reset to zero with no warning message.

GRU regeneration summary variables and land base summary variables in common GRUDET are computed.

Regular and donor acres, volumes, and volumes per acre after shifting are stored. Reguiar and donor acre totals are computed.

Subroutine GROW

Precommercially thinned acres and fertilized acres are recorded.

For growth using yield tables:

For stocking levels 1 to 3 of MI1 and MI's 2 to 5:

Acres in the next to the highest age class are added to acres in the highest age class.

Volume per acre for the highest age class is the product of standard volume for that age class times the stocking level midpoint for that MI and stocking level.

Volume for the highest age class is the product of acres and volume per acre.

For each age class from the next to highest down to the first:

Acres are moved from the age class below to that age class.

Volume per acre is the product of standard volume for that age class times the stocking level midpoint.

Volume is the product of acres times volume per acre.

Acres in the newly regenerated age class are set to zero.

For growth using the approach-to-normality equation:

Current normality is the stocking proportion before growth based on the values for the previous age class.

For any age class with zero standard volume, current normality is set to the stocking level midpoint for that MI and stocking level.

For all other age classes, current normality is the ratio of the sum of current volume per acre plus thinning volume per acre times the stocking level midpoint divided by standard volume.

Projected normality is the stocking proportion after growth computed for each age class.

For any age class with no existing acres, projected normality is set to zero.

For all other age classes less than or equal to the limit for full approach to normality, projected normality is the intercept of the approach-to-normality equation plus the slope of the equation times the current normality.

For all other age classes greater than the limit for full approach to normality and less than or equal to the limit for one-half the full approach-to-normality, projected normality is one-half the sum of the current normality plus the intercept of the equation plus the slope of the equation times the current normality.

For all other age classes greater than the limit for one-half the full approach to normality, projected normality is equal to current normality.

For stocking levels 1 to 3 of MI1 and MI's 2 to 5:

Acres in the next to highest age class are added to acres in the highest age class.

The acre-weighted average of projected normality for the highest age class and projected normality for the next to highest age class are computed.

For average projected normality less than or equal to the normality limit, volume per acre after growth for the highest age class is the product of the average projected normality times the standard volume for that age class, and volume after growth is the product of acres times volume per acre after growth.

For average projected normality greater than the normality limit, volume after growth is equal to volume before growth, and volume per acre after growth is the ratio of volume after growth divided by acres.

For age classes from the next to highest down to the first:

  Acres are moved from the age class below to that age class.

  For projected normality less than or equal to the normality limit, volume per acre after growth is the product of projected normality times the standard volume for that age class, and volume after growth is the product of acres times volume per acre after growth.

  For projected normality greater than the normality limit, volume after growth is equal to volume before growth, and volume per acre after growth is the ratio of volume after growth divided by acres.

  Acres in the newly regenerated age class are set to zero.

For donor acres that grow older, the acres in the next to highest age class are added to acres in the highest age class, and acres in all other age classes are moved up one age class.

Growth for stocking levels 1 to 3 of MI1 and MI's 2 to 5 is computed as the volume after growth less the volume before growth.

Growth summary variables in common GRUDET are computed.

Donor acre totals are recomputed.

Acres and volumes in stocking levels 1 to 3 of MI1 are shifted to the correct stocking level, depending on the stocking level entry points, and volumes per acre are recomputed.

MI1 total acres and volumes and average volumes per acre are recomputed.

Regular acre totals are recomputed.

Appendix E

Card-by-Card Input Formats

Columns:

1-5	7	9	11-12	21-30	31-40	41-50	51-60	61-70	71-80
BRU ID	Card type	mi	ac	Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
				Unstocked acres					
	1			UNSBRU					
				Donor acres for each donor, 1 and 2, and age class					
	2		ac	DONBRU (ac,1)	DONBRU (ac,2)				
				Regular acres and volumes per acre for MI 1, each stocking level, 1 to 3, and age class					
	3	1	ac	ACBRU (ac,1) stocking level 1	VPABRU(ac,1)	ACBRU(ac,2) stocking level 2	VPABRU(ac,2)	ACBRU(ac,3) stocking level 3	VPABRU(ac,3)
				Regular acres and volume per acre for MI's 2 to 5, stocking level 1, and age class					
	3	mi	ac	ACBRU(ac,mi+3)	VPABRU(ac,mi+3)				

Columns:

1-10	11-12	14	16	18-19	21-30	31-40	41-50	51-60	61-70	71-80
GRU ID	Card type	mi			Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
					GRU name: 15 character name					
	00				GRUNAM(to column 35)					
					BRU's belonging to GRU: BRU identification code and proportion of BRU included, if not = 1.0 (maximum = 50)					
	01				BRUID(i)	BRUID(j) or BRUPRO(i)	BRUID(k) or BRUPRO(j)	BRUID(l) or BRUPRO(k)	BRUID(m) or BRUPRO(l)	BRUID(n) or BRUPRO(m)
					GRU site and species					
	02				SITE Site	ORGSP Original Species	CVSP Conversion Species			
					GRU options					
	03				PNWRUN Rational expectation flag 0=off, 1=on	DUMP Diagnostic output flag 0=off, 1=on	IFDUMP First period for diagnostic output	LSDUMP Last period for diagnostic output		
					Planting stock for each MI, 1 to 5: blank for regular stock, 0 for genetic stock					
	04				PLANT(1)	PLANT(2)	PLANT(3)	PLANT(4)	PLANT(5)	
	05				Precommercial thinning age class for each MI, 1 to 5					
					PCTAGE(1)	PCTAGE(2)	PCTAGE(3)	PCTAGE(4)	PCTAGE(5)	
					Fertilization age class for each MI, 1 to 5, and applications, 1 and 2					
	06	mi			FTAGES(mi,1)	FTAGES(mi,2)				

Columns:

1-10	11-12	14	16	18-19	21-30	31-40	41-50	51-60	61-70	71-80
GRU ID	Card type	mifr	mito	pd	Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
					Age class limit for shifting among MI's					
	07	mifr	mito		HISHIF(mifr, mito)					
					Minimum harvest age class for each MI, 1 to 5					
	08				MINHAR(1)	MINHAR(2)	MINHAR(3)	MINHAR(4)	MINHAR(5)	
					Rotation age for each MI, 1 to 5 (age in years)					
	09				ROT(1)	ROT(2)	ROT(3)	ROT(4)	ROT(5)	
					Discount rate for period					
	10				DISCO(-1) Fill value					
	10			pd	DISCO(pd)	DISCO(pd+1)	DISCO(pd+2)	DISCO(pd+3)	DISCO(pd+4)	DISCO(pd+5)
					Price per unit for period					
	11				PRICE(-1) Fill value					
	11			pd	PRICE(pd)	PRICE(pd+1)	PRICE(pd+2)	PRICE(pd+3)	PRICE(pd+4)	PRICE(pd+5)
	12				Annual cost per acre for period					
	12				ANNCO(-1) Fill value					
	12			pd	ANNCO(pd)	ANNCO(pd+1)	ANNCO(pd+2)	ANNCO(pd+3)	ANNCO(pd+4)	ANNCO(pd+5)

Columns

1-10	11-12	14	16	18-19	21-30	31-40	41-50	51-60	61-70	71-80
GRU ID	Card type			pd	Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
					Final harvest cost per unit for period					
	13				HARUNT(-1) Fill value					
	13			pd	HARUNT (pd)	HARUNT(pd+1)	HARUNT(pd+2)	HARUNT(pd+3)	HARUNT(pd+4)	HARUNT(pd+5)
					Final harvest cost per acre for period					
	14			pd	HARCO(-1) Fill value					
	14			pd	HARCO(pd)	HARCO(pd+1)	HARCO(pd+2)	HARCO(pd+3)	HARCO(pd+4)	HARCO(pd+5)
					Commercial thinning cost per unit for period					
	15				CTUNIT(-1) Fill value					
	15			pd	CTUNIT(pd)	CTUNIT(pd+1)	CTUNIT(pd+2)	CTUNIT(pd+3)	CTUNIT(pd+4)	CTUNIT(pd+5)
					Commercial thinning cost per acre for period					
	16				CTCO(-1) Fill value					
	16			pd	CTCO(pd)	CTCO(pd+1)	CTCO(pd+2)	CTCO(pd+3)	CTCO(pd+4)	CTCO(pd+5)
					Fertilization cost per acre for period					
	17				FERTCO(-1) Fill value					
	17			pd	FERTCO(pd)	FERTCO(pd+1)	FERTCO(pd+2)	FERTCO(pd+3)	FERTCO(pd+4)	FERTCO(pd+5)

Columns:

1-10	11-12	14	16	18-19	21-30	31-40	41-50	51-60	61-70	71-80
GRU ID	Card type	mi		pd	Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
					Precommercial thinning cost per acre for period					
	18				PCTCO(-1) Fill value					
	18			pd	PCTCO(pd)	PCTCO(pd+1)	PCTCO(pd+2)	PCTCO(pd+3)	PCTCO(pd+4)	PCTCO(pd+5)
					Regeneration cost per cut acre for MI and period					
	19	mi			REGECO(-1,mi) Fill value					
	19	mi		pd	REGECO(pd,mi)	REGECO(pd+1,mi)	REGECO(pd+2,mi)	REGECO(pd+3,mi)	REGECO(pd+4,mi)	REGECO(pd+5,mi)
					Regeneration cost per unstocked acre for MI and period					
	20	mi			UNSTCO(-1,mi) Fill value					
	20	mi		pd	UNSTCO(pd,mi)	UNSTCO(pd+1,mi)	UNSTCO(pd+2,mi)	UNSTCO(pd+3,mi)	UNSTCO(pd+4,mi)	UNSTCO(pd+5,mi)
					Proportion of unstocked acres restocked for period					
	21				UNSTRE(-1) Fill value					
	21			pd	UNSTRE(pd)	UNSTRE(pd+1)	UNSTRE(pd+2)	UNSTRE(pd+3)	UNSTRE(pd+4)	UNSTRE(pd+5)
					Proportion of cut acres to unstocked for period					
	22				CUTUNS(-1) Fill value					
	22			pd	CUTUNS(pd)	CUTUNS(pd+1)	CUTUNS(pd+2)	CUTUNS(pd+3)	CUTUNS(pd+4)	CUTUNS(pd+5)

Columns:

1-10	11-12	14	16	18-19	21-30	31-40	41-50	51-60	61-70	71-80
GRU ID	Card type	od mifr	mito od	pd	Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
					Stocking level midpoint for MI 1, stocking levels 1 to 3; proportion of MI 1 acres regenerated in each stocking level, 1 to 3					
	23				SLMID(1)	SLMID(2)	SLMID(3)	SLDIST(1)	SLDIST(2)	SLDIST(3)
					Minimum stocking proportion to enter stocking levels 1 and 2; stocking level midpoint for stocking level 1 of MI 2 to 5 (MT 5 to 8)					
	24				SLMIN(1)	SLMIN(2)	SLMID(5)	SLMID(6)	SLMID(7)	SLMID(8)
					Stocking level of each donor, 1 and 2					
	25				ODSTOC(1)	ODSTOC(2)				
					Proportion of donor acres to shift to MI for period					
	26	od	mito		DONOR(-1,od,mito) Fill value					
	26	od	mito	pd	DONOR(pd,od, mito)	DONOR(pd+1, od,mito)	DONOR(pd+2, od,mito)	DONOR(pd+3, od,mito)	DONOR(pd+4, od,mito)	DONOR(pd+5, od,mito)
					Proportion of MI acres to shift to donor for period					
	27	mifr	od		MIOUT(-1, mifr,od) Fill value					
	27	mifr	od	pd	MIOUT(pd, mifr,od)	MIOUT(pd+1, mifr,od)	MIOUT(pd+2, mifr,od)	MIOUT(pd+3, mifr,od)	MIOUT(pd+4, mifr,od)	MIOUT(pd+5, mifr,od)
					Preselected proportion to shift among MI's for period					
	28	mifr	mito		MISHIF(-1, mifr, mito) Fill value					
	28	mifr	mito	pd	MISHIF(pd, mifr,mito)	MISHIF(pd+1, mifr,mito)	MISHIF(pd+2, mifr,mito)	MISHIF(pd+3, mifr,mito)	MISHIF(pd+4, mifr,mito)	MISHIF(pd+5) mifr,mito)

Columns:

1-10	11-12	14	16	18-19	21-30	31-40	41-50	51-60	61-70	71-80
GRU ID	Card type	od, mi		pd, ac	Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
					Exogenous volume proportion recovered from donor acres for period					
	29	od			DONCAP(-1,od) Fill value					
	29	od		pd	DONCAP(pd,od)	DONCAP(pd+1,od)	DONCAP(pd+2,od)	DONCAP(pd+3,od)	DONCAP(pd+4,od)	DONCAP(pd+5,od)
					Growth type and approach to normality					
	30				GROTYP Growth type 0=yield table 1=approach-to normality	FULLAP Last age class for full approach-to-normality	HALFAP Last age class for one half the full approach-to-normality	INTAP Intercept of approach-to-normality function	COEFAP Coefficient of approach-to-normality function	
					Mortality salvage					
	31				MORSAL Mortality salvage flag 0=off, 1=on	MORPRP Salvable proportion of mortality volume	MORVOL Minimum salvable volume per acre			
					Average diameter for MI and age class					
	32	mi			AVDIAM(-1,mi) Fill value					
	32	mi		ac	AVDIAM(ac,mi)	AVDIAM(ac+1,mi)	AVDIAM(ac+2,mi)	AVDIAM(ac+3,mi)	AVDIAM(ac+4,mi)	AVDIAM(ac+5,mi)
					Standard net volume per acre for MI and age class					
	33	mi			VOLPA(-1,mi) Fill value					
	33	mi		ac	VOLPA(ac,mi)	VOLPA(ac+1,mi)	VOLPA(ac+2,mi)	VOLPA(ac+3,mi)	VOLPA(ac+4,mi)	VOLPA(ac+5,mi)

Columns:

1-10	11-12	14	16	18-19	21-30	31-40	41-50	51-60	61-70	71-80
GRU ID	Card type	mi		ac	Data field 1	Data field 2	Data field 3	Data field 4	Data field 5	Data field 6
					Thinning volume per acre for MI and age class					
	34	mi			THINPA(-1,mi) Fill value					
	34	mi		ac	THINPA(ac,mi)	THINPA(ac+1,mi)	THINPA(ac+2,mi)	THINPA(ac+3,mi)	THINPA(ac+4,mi)	THINPA(ac+5,mi)
					Mortality volume per acre for MI and age class					
	35	mi			MORTPA(-1,mi) Fill value					
	35	mi		ac	MORTPA(ac,mi)	MORTPA(ac+1,mi)	MORTPA(ac+2,mi)	MORTPA(ac+3,mi)	MORTPA(ac+4,mi)	MORTPA(ac+5,mi)
					Softwood proportion of volume per acre for MI and age class					
	36	mi			SOFTPA(-1,mi) Fill value					
	36	mi		ac	SOFTPA(ac,mi)	SOFTPA(ac+1,mi)	SOFTPA(ac+2,mi)	SOFTPA(ac+3,mi)	SOFTPA(ac+4,mi)	SOFTPA(ac+5,mi)
					Adjustment factor for growth on harvest for MI and age class					
	37	mi			HARGRO(-1,mi) Fill value					
	37	mi		ac	HARGRO(ac,mi)	HARGRO(ac+1,mi)	HARGRO(ac+2,mi)	HARGRO(ac+3,mi)	HARGRO(ac+4,mi)	HARGRO(ac+5,mi)
					Preferred harvest proportion for age class					
	38				HVPROP(-1) Fill value					
	38			ac	HVPROP(ac)	HVPROP(ac+1)	HVPROP(ac+2)	HVPROP(ac+3)	HVPROP(ac+4)	HVPROP(ac+5)
					Volume conversion factor for age class (to convert from base volume unit to alternate volume unit)					
	39				CONFAC(-1) Fill value					
	39			ac	CONFAC(ac)	CONFAC(ac+1)	CONFAC(ac+2)	CONFAC(ac+3)	CONFAC(ac+4)	CONFAC(ac+5)

Columns:

1-2	3-5	7	10-11	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80
Card type	ac, rt	ht	pd												
				Run header											
01				RHEAD 60 characters run description											
				Time information											
02				STYEAR Starting Year		LENPD Number of years per period		MAXPD Last period of run		APLIM Normality limit for changing		APMIN Normality minimum for warning		APMAX Normality maximum for warning	
				Age class report groups: 8 groups possible											
03	ac			ACGRP(ac) Age class report group											
				Unit conversion specifications (for alternate inventory and/or harvest report)											
04				ALTUNT 15 character label for the units after conversion				DIAMIN Minimum diameter for conversion							
				Report Matrix: 0=no, 1=yes; rt=1 for GRU detail, =2 for ACU detail, = 3 for ACU summary, =4 for ACU subgroup summary, =5 for summary totals											
05	rt	(report name optional in 8-20)		REPMAT(rt,1) Inventory		REPMAT(rt,2) Harvest		REPMAT(rt,3) Alternate unit inventory and/or harvest		REPMAT(rt,4) Regeneration and treatment		REPMAT(rt,5) Economic		REPMAT(rt,6) Land shift	
				ACU subgroups: (maximum=12)											
06				Subgroup n				Subgroup n+1				Subgroup n+2			

Columns:

1-2	3-5	7	10-11	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80
Card type	ACU	ht, ct	pd												
				ACU name											
A1				ACUNAM 15 character label for ACU											
				GRU's belonging to ACU (maximum is 50)											
A2				GRUID(n)		GRUID(n+1)		GRUID(n+2)		GRUID(n+3)		GRUID(n+4)		GRUID(n+5)	
				ACU harvest volume for period: ht=1 for softwood, =2 for hardwood, =3 for combined											
A3		ht	pd	HRVACU(pd)			HRVACU(pd+1)			HRVACU(pd+2)			HRVACU(pd+3)		
				ACU shift specification											
A4				DONTOP Donor 2 shift method 1=acres grow older 2=acres frozen in age 3=acres in pool, existing distribution											
				ACU treatment name: one card for each ct, 1 to 7, required											
A5		ct		TRNAME(ct) 15-character label for treatment											
				ACU management intensity name: one card for each ct, 1 to 5, required											
A6		ct		MINAME(ct) 15-character label for management intensity											

Columns:

1-2	3-5	7	10-11	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80
Card type	ACU	ct	ac												
				ACU site name: one card for each ct, 1 to 3, required											
A7		ct		SITNAM(ct) 15-character label for site											
				ACU species name and report group: one card for each species, ct may be 1 to 9											
A8		ct		SPNAME(ct) 15-character label for species				SPGRP(ct) Species report group 1=softwood, 2=hardwood							

Appendix F

Example: TRIM Inputs and Results

The minimum data—It is possible to make a TRIM system run with a minimum level of data. The minimum data option is very helpful when debugging input values or when a particular report is needed to check inventory totals, etc. Default values are provided for most of the data required for a TRIM run. The minimum information is an inventory, an appropriate volume table, harvest amounts requested, label information, and a few other parameters.

The TRIM user must start with the initial inventory to be used and prepare that inventory in the proper format by following the instructions and formats for the BRU. Each BRU must be assigned an identification code (up to five digits). Figure 7 illustrates BRU number 41001 (comment cards are indicated by a double asterisk and are not necessary). The BRU has no unstocked acres, no donor acres, and acres and volume from age class 0 to age class 7. Age class 6 has 37,754.4 acres with an average volume per acre of 6022.92 cubic feet. There are no acres in stocking levels 2 or 3.

When the BRU inventory is properly coded, the GRU must be constructed. The GRU contains the normal volume tables and management instructions for current and future management of the BRU's belonging to the GRU. Again, each GRU must have an identification code (up to 10 digits). Figure 8 illustrates the minimum requirements for a GRU. The first card indicates the BRU number, the second indicates site and species code, and the final 3 cards are the normal volumes per acre. As there is no approach-to-normality in this GRU, the acres in the BRU will grow and be assigned the yield table values after the 0 period.

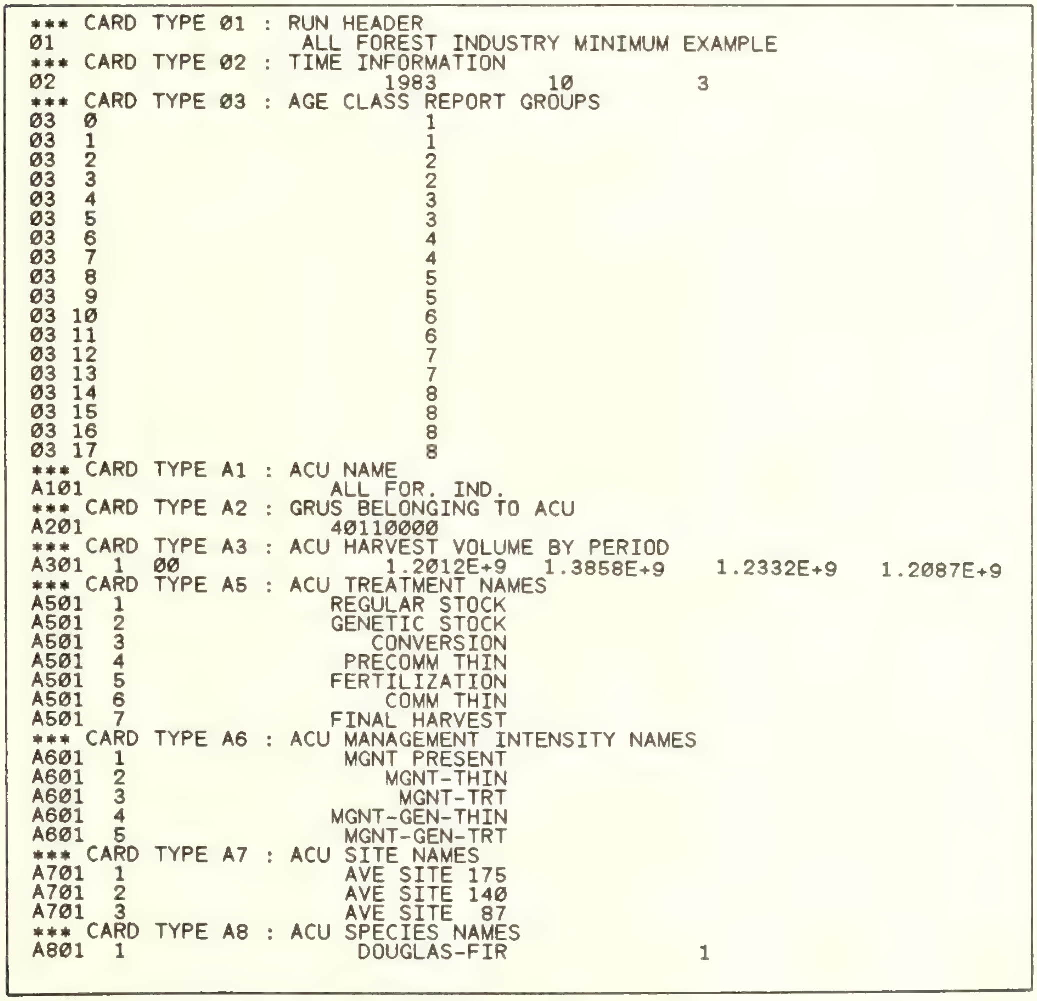
```
*** INVENTORY EXAMPLE FOR ALL FOREST INDUSTRY HIGH
*** CARD TYPE 3   : REGULAR ACRES, VOLUMES PER ACRE
41001 3 1  0          190946.1     24.03
41001 3 1  1          115739.7    459.42
41001 3 1  2          156021.0   2014.75
41001 3 1  3          276580.5   4086.52
41001 3 1  4          132144.2   5138.46
41001 3 1  5           28743.4   4130.53
41001 3 1  6           37754.4   6022.92
41001 3 1  7           54735.9   5821.25
41001 3 1  8            6323.3   3875.80
41001 3 1  9           11678.6  10590.00
41001 3 1 10            9181.3   1583.40
```

Figure 7—Minimum data BRU file.

```
*** CONTROL FILE FOR MINIMUM DATA EXAMPLE
*** CARD TYPE 00 : GRU NAME
40110000  00        ALL FOR IND HI
*** CARD TYPE 01 : BRUS BELONGING TO GRU
40110000  01              41001
*** CARD TYPE 02 : GRU SITE AND SPECIES
40110000  02               1         1
*** CARD TYPE 33 : GRU STANDARD VOLUME PER ACRE BY MI BY AC
40110000  33 1    0       5.0      12.0    1163.0    4288.0    7744.0   11092.0
40110000  33 1    6   13867.0   16110.0   18020.0   19676.0   21117.0   22377.0
40110000  33 1   12   23486.0   23486.0   23486.0   23486.0   23486.0   23486.0
```

Figure 8—Minimum data GRU file.

Run header parameters are the next requirements. A run header, the starting year of the simulation, the number of years in a period, and the length of the simulation in periods must be supplied as well as age-class report groups. The top portion of figure 9 illustrates the run header information. The first card is the title of the simulation. The second card indicates the starting time period (1983), the length of each period (10 years), and the number of periods in this simulation (3). The second series of cards (card 03) group the 18 age classes into 8 report groups. For example, those acres in age classes 0 and 1 will be reported together in age class report group 1.

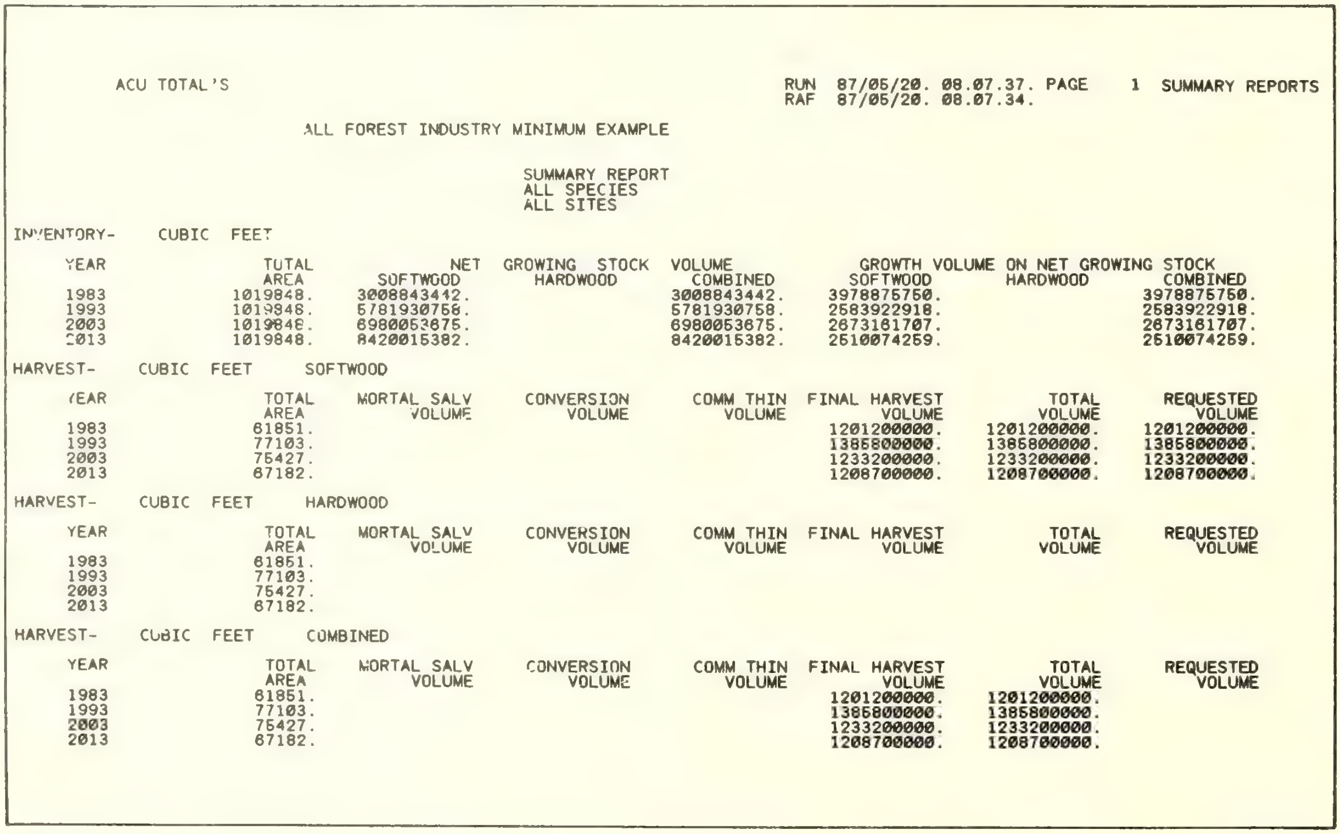


```
*** CARD TYPE 01 : RUN HEADER
01                  ALL FOREST INDUSTRY MINIMUM EXAMPLE
*** CARD TYPE 02 : TIME INFORMATION
02                        1983        10         3
*** CARD TYPE 03 : AGE CLASS REPORT GROUPS
03  0                        1
03  1                        1
03  2                        2
03  3                        2
03  4                        3
03  5                        3
03  6                        4
03  7                        4
03  8                        5
03  9                        5
03 10                        6
03 11                        6
03 12                        7
03 13                        7
03 14                        8
03 15                        8
03 16                        8
03 17                        8
*** CARD TYPE A1 : ACU NAME
A101                  ALL FOR. IND.
*** CARD TYPE A2 : GRUS BELONGING TO ACU
A201                  40110000
*** CARD TYPE A3 : ACU HARVEST VOLUME BY PERIOD
A301  1  00               1.2012E+9   1.3858E+9    1.2332E+9    1.2087E+9
*** CARD TYPE A5 : ACU TREATMENT NAMES
A501  1               REGULAR STOCK
A501  2               GENETIC STOCK
A501  3                  CONVERSION
A501  4                PRECOMM THIN
A501  5               FERTILIZATION
A501  6                   COMM THIN
A501  7               FINAL HARVEST
*** CARD TYPE A6 : ACU MANAGEMENT INTENSITY NAMES
A601  1                MGNT PRESENT
A601  2                   MGNT-THIN
A601  3                    MGNT-TRT
A601  4               MGNT-GEN-THIN
A601  5                MGNT-GEN-TRT
*** CARD TYPE A7 : ACU SITE NAMES
A701  1                AVE SITE 175
A701  2                AVE SITE 140
A701  3                AVE SITE  87
*** CARD TYPE A8 : ACU SPECIES NAMES
A801  1                 DOUGLAS-FIR                1
```

Figure 9—Minimum data ACU file.

The ACU must now be specified. Various labels must be supplied for each ACU. The ACU name, the list of GRU's belonging to the ACU, and harvest fiber type and amount must be identified. Names for treatments, management intensities, and sites are also required. Species name and species report group must match the species code in the GRU information. Figure 9 illustrates the ACU file. Card A101 lists the name of the ACU (ALL FOR. IND.) and card A201 lists the GRU's belonging to this ACU (there is only one, 4011000). Card A301 lists the harvest fiber type 1 (softwood) and the amount of harvest volume to be taken for each period. There are four entries because period 0 is a removal period and the run length is 3 periods. The final four card types (A501, A601, A701, and A801) represent the labels and names required by the reports. These should match data inputs for the treatments, management intensities, and site and species names.

Figure 10 represents the minimum level of output or the summary report for all sites and species. The date and time of the TRIM run and the RAF creation can be located in the upper right corner. The output lists the inventory, growth, and harvest for both softwood and hardwood, and the totals. Because there was no softwood proportion of total volume in this run the hardwood reports are blank.



```
           ACU TOTAL'S                                                           RUN  87/05/20. 08.07.37. PAGE       1  SUMMARY REPORTS
                                                                                 RAF  87/05/20. 08.07.34.

                               ALL FOREST INDUSTRY MINIMUM EXAMPLE

                                                     SUMMARY REPORT
                                                     ALL SPECIES
                                                     ALL SITES
INVENTORY-     CUBIC   FEET

     YEAR                TOTAL                NET  GROWING  STOCK  VOLUME               GROWTH VOLUME ON NET GROWING STOCK
                          AREA        SOFTWOOD         HARDWOOD        COMBINED         SOFTWOOD        HARDWOOD          COMBINED
      1983             1019848.     3008843442.                      3008843442.      3978875750.                      3978875750.
      1993             1019848.     5781930758.                      5781930758.      2583922918.                      2583922918.
      2003             1019848.     6980053675.                      6980053675.      2673161707.                      2673161707.
      2013             1019848.     8420015382.                      8420015382.      2510074259.                      2510074259.
HARVEST-     CUBIC   FEET      SOFTWOOD

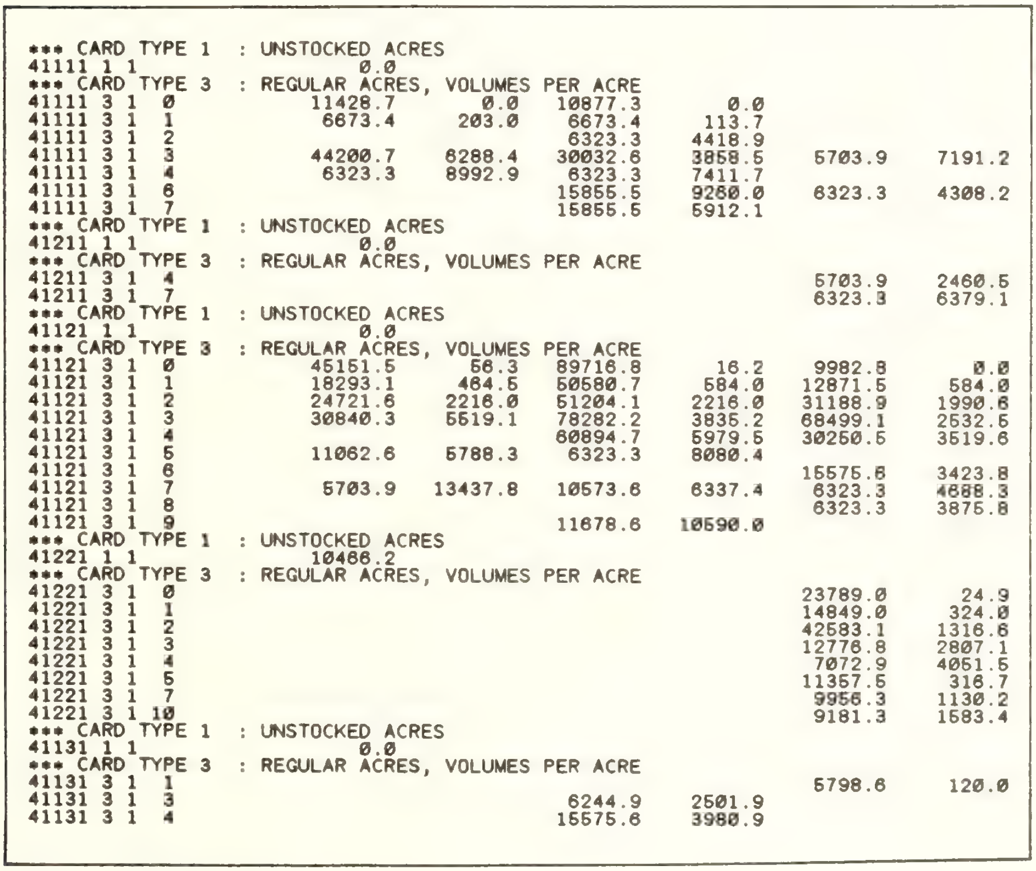
     YEAR                TOTAL     MORTAL SALV       CONVERSION       COMM THIN   FINAL HARVEST              TOTAL      REQUESTED
                          AREA           VOLUME           VOLUME          VOLUME          VOLUME             VOLUME         VOLUME
      1983               61851.                                                        1201200000.      1201200000.     1201200000.
      1993               77103.                                                        1385800000.      1385800000.     1385800000.
      2003               75427.                                                        1233200000.      1233200000.     1233200000.
      2013               67182.                                                        1208700000.      1208700000.     1208700000.
HARVEST-     CUBIC   FEET      HARDWOOD

     YEAR                TOTAL     MORTAL SALV       CONVERSION       COMM THIN   FINAL HARVEST              TOTAL      REQUESTED
                          AREA           VOLUME           VOLUME          VOLUME          VOLUME             VOLUME         VOLUME
      1983               61851.
      1993               77103.
      2003               75427.
      2013               67182.
HARVEST-     CUBIC   FEET      COMBINED

     YEAR                TOTAL     MORTAL SALV       CONVERSION       COMM THIN   FINAL HARVEST              TOTAL      REQUESTED
                          AREA           VOLUME           VOLUME          VOLUME          VOLUME             VOLUME         VOLUME
      1983               61851.                                                        1201200000.      1201200000.
      1993               77103.                                                        1385800000.      1385800000.
      2003               75427.                                                        1233200000.      1233200000.
      2013               67182.                                                        1208700000.      1208700000.
```

Figure 10—Minimum data summary output.

Detailed input.—The final example illustrates a TRIM system input and simulation that is more complex in terms of input. This example includes only one GRU however. Figure 11 illustrates the five BRU's in this simulation: BRU's numbered 41111 to 41131. There are unstocked acres in BRU 41221, and there are no donor acres in any of the BRU's. The acres are distributed among the three different stocking levels.



```
*** CARD TYPE 1   : UNSTOCKED ACRES
41111 1 1                     0.0
*** CARD TYPE 3   : REGULAR ACRES, VOLUMES PER ACRE
41111 3 1  0              11428.7       0.0  10877.3       0.0
41111 3 1  1               6673.4     203.0   6673.4     113.7
41111 3 1  2                                  6323.3    4418.9
41111 3 1  3              44200.7    6288.4  30032.6    3858.5    5703.9    7191.2
41111 3 1  4               6323.3    8992.9   6323.3    7411.7
41111 3 1  6                                 15855.5    9260.0    6323.3    4308.2
41111 3 1  7                                 15855.5    5912.1
*** CARD TYPE 1   : UNSTOCKED ACRES
41211 1 1                     0.0
*** CARD TYPE 3   : REGULAR ACRES, VOLUMES PER ACRE
41211 3 1  4                                                      5703.9    2460.5
41211 3 1  7                                                      6323.3    6379.1
*** CARD TYPE 1   : UNSTOCKED ACRES
41121 1 1                     0.0
*** CARD TYPE 3   : REGULAR ACRES, VOLUMES PER ACRE
41121 3 1  0              45151.5      56.3  89716.8      16.2    9982.8       0.0
41121 3 1  1              18293.1     464.5  50580.7     584.0   12871.5     584.0
41121 3 1  2              24721.6    2216.0  51204.1    2216.0   31188.9    1990.6
41121 3 1  3              30840.3    5519.1  78282.2    3835.2   68499.1    2532.5
41121 3 1  4                                 60894.7    5979.5   30250.5    3519.6
41121 3 1  5              11062.6    5788.3   6323.3    8080.4
41121 3 1  6                                                     15575.6    3423.8
41121 3 1  7               5703.9   13437.8  10573.6    6337.4    6323.3    4688.3
41121 3 1  8                                                      6323.3    3875.8
41121 3 1  9                                 11678.6   10590.0
*** CARD TYPE 1   : UNSTOCKED ACRES
41221 1 1                 10486.2
*** CARD TYPE 3   : REGULAR ACRES, VOLUMES PER ACRE
41221 3 1  0                                                     23789.0      24.9
41221 3 1  1                                                     14849.0     324.0
41221 3 1  2                                                     42583.1    1316.6
41221 3 1  3                                                     12776.8    2807.1
41221 3 1  4                                                      7072.9    4051.5
41221 3 1  5                                                     11357.5     316.7
41221 3 1  7                                                      9956.3    1130.2
41221 3 1 10                                                      9181.3    1583.4
*** CARD TYPE 1   : UNSTOCKED ACRES
41131 1 1                     0.0
*** CARD TYPE 3   : REGULAR ACRES, VOLUMES PER ACRE
41131 3 1  1                                                      5798.6     120.0
41131 3 1  3                                  6244.9    2501.9
41131 3 1  4                                 15575.6    3980.9
```

Figure 11—Detailed data BRU file.

The GRU input is presented in figure 12.[1] This GRU is entitled "FOREST IND. HIGH" and has five BRU's in it as can be seen from the first two card entries. GRU card 2 indicates the site and species, and cards 5, 7, and 8 set up precommercial thinning ages, age limit for shifts to higher MI's, and minimum harvest ages. The block of economic cards, GRU cards 11 through 20, indicate the different costs of treatment and harvests along with the price per unit harvested. The next set of cards, GRU cards 21 through 28, represents current and future levels of stocking, how the acres are to be shifted between the unstocked acres, and how they will shift between the two different management intensities. In this example, card 28 indicates that acres will move between MI1 and MI2 at rates of 33 percent, 50 percent, and 100 percent for the first three periods. If all acres in MI1 were in stocking level 1 and all acres were harvested during the simulation, then all acres could conceivably end up in MI2. The final set of cards indicates the type of growth, approach-to-normality, the diameter and yield tables for both management intensities, thinning yields for MI2, mortality volume, and softwood proportions. The default is harvest the oldest first and there will be no conversion reports because there are no card 39's.

---

[1] The input data and example output in figures 12 through 14 are for illustrative purposes only.

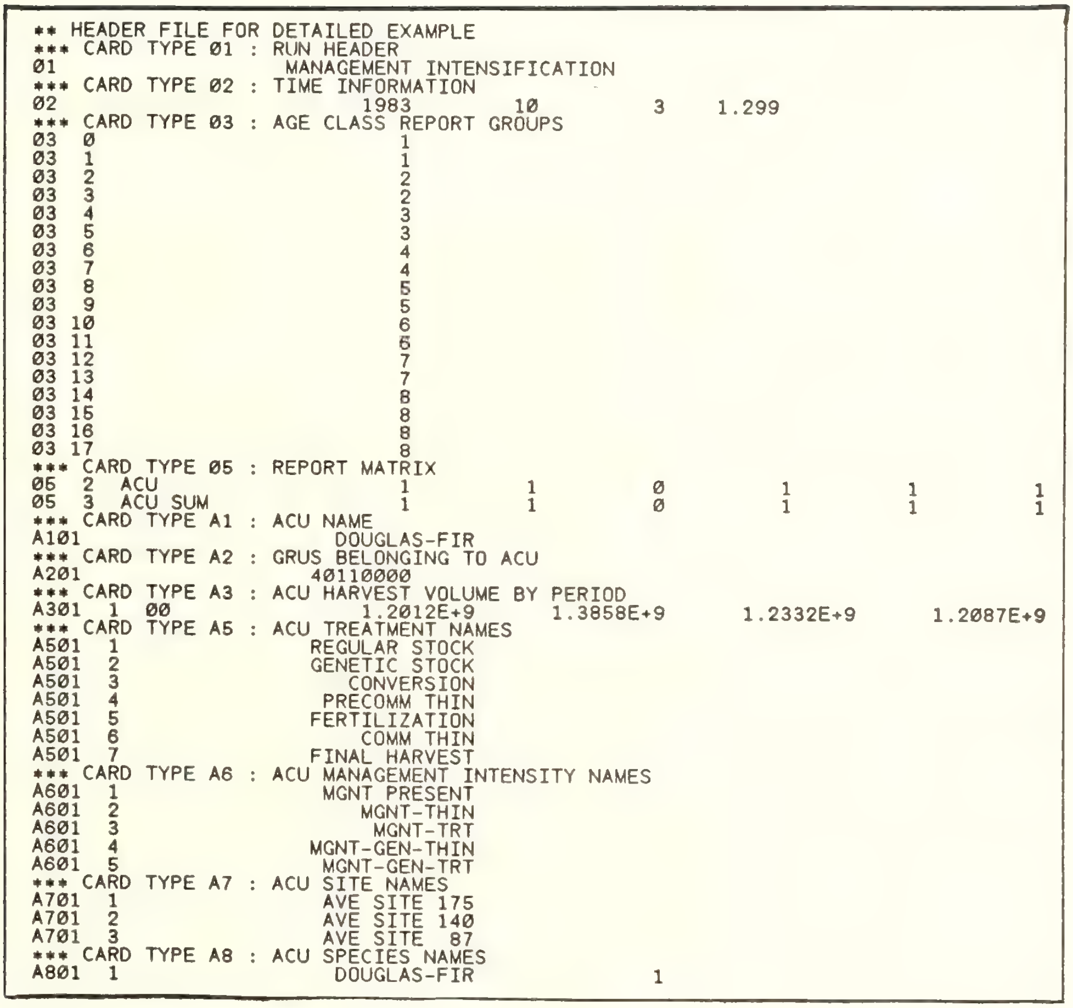
```
*** CONTROL FILE FOR DETAILED EXAMPLE
*** CARD TYPE 00 : GRU NAME
40110000  00          FOR. IND.  HIGH
*** CARD TYPE 01 : BRUS BELONGING TO GRU
40110000  01               41111     41211     41121     41131     41221
*** CARD TYPE 02 : GRU SITE AND SPECIES
40110000  02                   1         1
*** CARD TYPE 04 : G~) PLANTING TYPES BY MI
40110000  04                                                 0         0
*** CARD TYPE 05 : GRU PRECOMMERCIAL THINNING AGES BY MI
40110000  05                   1         1         1         1         1
*** CARD TYPE 06 : GRU FERTILIZATION AGES BY MI
40110000  06 3                 3
40110000  06 5                 2         3
*** CARD TYPE 07 : GRU AGE LIMITS FOR SHIFTING BY MI
40110000  07 1 2               3
40110000  07 1 3               3
40110000  07 1 4               0
40110000  07 1 5               0
40110000  07 2 3               3
40110000  07 2 4               0
40110000  07 2 5               0
40110000  07 3 4               0
40110000  07 3 5               0
40110000  07 4 5               2
*** CARD TYPE 08 : GRU MINIMUM HARVEST AGES BY MI
40110000  08                   4         4         4         4         4
*** CARD TYPE 09 : GRU ROTATION AGES BY MI
40110000  09                  80        80        80        80        80
*** CARD TYPE 10 : GRU DISCOUNT RATES BY PERIOD
40110000  10                 .04
*** CARD TYPE 11 : GRU PRICES PER UNIT BY PERIOD
40110000  11      00        3.00      3.09      3.18      3.28
*** CARD TYPE 12 : GRU ANNUAL COSTS PER ACRE BY PERIOD
40110000  12      00        3.00      3.06      3.12      3.18
*** CARD TYPE 15 : GRU COMMERCIAL THINNING COST PER UNIT BY PERIOD
40110000  15      00       .4160     .4280     .4413     .4545
*** CARD TYPE 16 : GRU COMMERCIAL THINNING COST PER ACRE BY PERIOD
40110000  16      00       290.0     298.7     307.6     316.9
*** CARD TYPE 17 : GRU FERTILIZATION COST PER ACRE BY PERIOD
40110000  17      00        33.0      33.9      35.0      36.0
*** CARD TYPE 18 : GRU PERCOMMERCIAL THINNING COST PER ACRE BY PERIOD
40110000  18      00        77.0      79.3      81.7     84.14
*** CARD TYPE 19 : GRU REGENERATION COST PER CUT ACRE BY MI BY PERIOD
40110000  19 1    00       114.0     117.4     120.9     124.6
40110000  19 2    00       114.0     117.4     120.9     124.6
40110000  19 3    00       114.0     117.4     120.9     124.6
40110000  19 4    00       134.0     138.0     142.2     146.4
40110000  19 5    00       134.0     138.0     142.2     146.4
*** CARD TYPE 20 : GRU REGENERATION COST PER UNSTOCKED ACRE BY MI BY PERIOD
40110000  20 1    00       186.0     191.6     197.3     203.2
40110000  20 2    00       186.0     191.6     197.3     203.2
40110000  20 3    00       186.0     191.6     197.3     203.2
40110000  20 4    00       206.0     212.2     218.5     225.1
40110000  20 5    00       206.0     212.2     218.5     225.1
*** CARD TYPE 23 : GRU MI 1 STOCKING LEVEL MIDPOINTS, DISTRIBUTION
40110000  23                 .78       .54       .32       .23       .60       .17
*** CARD TYPE 24 : GRU MI 1 ENTRY LEVELS, MI 2 - 5 STOCKING LEVEL MIDPOINTS
40110000  24                 .70       .40      1.00      1.00      1.00      1.00
*** CARD TYPE 28 : GRU PRESELECTED SHIFTS AMONG MIS BY PERIOD
40110000  28 1 2 00          .33       .50       1.0       0.0
*** CARD TYPE 30 : GRU GROWTH TYPE , APPROACH TO NORMAL
40110000  30                   1         8        17 5.315E-02  9.28E-01
*** CARD TYPE 31 : GRU MORTALITY SALVAGE
40110000  31                   1       .60      800.
*** CARD TYPE 32 : GRU AVERAGE DIAMETER BY MI BY AC
40110000  32 1     0         0.0       1.2       6.4       9.9      12.8      15.2
40110000  32 1     6        17.2      19.3      21.1      22.7      24.3      25.8
40110000  32 1    12        27.4      27.4      27.4      27.4      27.4      27.4
40110000  32 2     0         0.0       1.2       6.4      11.9      16.8      20.1
40110000  32 2     6        22.7      25.2      27.4      29.4      31.4      33.3
40110000  32 2    12        35.3      35.3      35.3      35.3      35.3      35.3
40110000  32 3     0         0.0       1.2       6.4      12.3      19.1      23.4
40110000  32 3     6        26.8      29.9      32.9      35.6      38.0      40.4
40110000  32 3    12        42.8      42.8      42.8      42.8      42.8      42.8
40110000  32 4     0         0.0       1.3       7.0      13.1      18.5      22.1
40110000  32 4     6        25.0      27.7      30.1      32.3      34.5      36.6
```

Figure 12—Detailed data GRU file.

```
40110000  32 4   12       38.8       38.8       38.8       38.8       38.8       38.8
40110000  32 5    0        0.0        1.3        7.0       10.3       18.6       22.6
40110000  32 5    6       25.5       28.4       31.0       33.3       35.6       37.7
40110000  32 5   12       40.2       40.2       40.2       40.2       40.2       40.0
*** CARD TYPE 33 : GRU STANDARD VOLUME PER ACRE BY MI BY AC
40110000  33 1    0        5.0       12.0     1163.0     4288.0     7744.0    11092.0
40110000  33 1    6    13867.0    16110.0    18020.0    19676.0    21117.0    22377.0
40110000  33 1   12    23486.0    23486.0    23486.0    23486.0    23486.0    23486.0
40110000  33 2    0        5.0       12.0     1163.0     2922.0     4659.0     7771.0
40110000  33 2    6    10904.0    13810.0    16564.0    19095.0    21395.0    23202.0
40110000  33 2   12    24643.0    24643.0    24643.0    24643.0    24643.0    24643.0
40110000  33 3    0        5.0       12.0     1163.0     3111.0     3882.0     6748.0
40110000  33 3    6     9775.0    12732.0    15433.0    18069.0    20610.0    22971.0
40110000  33 3   12    24873.0    24873.0    24873.0    24873.0    24873.0    24873.0
40110000  33 4    0        5.0       13.2     1279.3     3214.2     5124.9     8548.1
40110000  33 4    6    11999.4    15191.0    18220.4    21004.5    23534.5    25522.2
40110000  33 4   12    27107.3    27107.3    27107.3    27107.3    27107.3    27107.3
40110000  33 5    0        5.0       13.2     1279.3     5238.2     4776.2     8080.6
40110000  33 5    6    11473.0    14659.7    17605.5    20395.1    23014.2    25379.2
40110000  33 5   12    27251.4    27251.4    27251.4    27251.4    27251.4    27251.4
*** CARD TYPE 34 : GRU THINNING VOLUME PER ACRE BY MI BY AC
40110000  34 2    0        0.0        0.0        0.0     1139.0     1365.0        0.0
40110000  34 3    0        0.0        0.0        0.0     1139.0     2377.0        0.0
40110000  34 4    0        0.0        0.0        0.0     1252.9     1501.5        0.0
40110000  34 5    0        0.0        0.0        0.0     2138.4     2241.8        0.0
*** CARD TYPE 35 : GRU MORTALITY VOLUME PER ACRE BY MI BY AC
40110000  35 1    0        0.0        0.0        2.0       58.0      349.0      563.0
40110000  35 1    6     1048.0     1324.0     1422.0     1468.0     1492.0     1500.0
40110000  35 1   12     1190.0     1100.0     1000.0      950.0      900.0      875.0
40110000  35 2    0        0.0        0.0        2.0       10.0       11.0       26.0
40110000  35 2    6      126.0      312.0      405.0      549.0      713.0     1057.0
40110000  35 2   12     1124.0     1100.0     1050.0     1000.0      950.0      925.0
40110000  35 3    0        0.0        0.0        2.0       13.0       14.0       13.0
40110000  35 3    6       33.0      143.0      384.0      372.0      427.0      507.0
40110000  35 3   12      758.0      850.0     1000.0      950.0      900.0      875.0
40110000  35 4    0        0.0        0.0        2.0       10.0       11.0       26.0
40110000  35 4    6      126.0      312.0      405.0      549.0      713.0     1057.0
40110000  35 4   12     1124.0     1100.0     1050.0     1000.0      950.0      925.0
40110000  35 5    0        0.0        0.0        2.0       65.0       17.0       19.0
40110000  35 5    6       71.0      261.0      404.0      474.0      575.0      707.0
40110000  35 5   12      907.0     1000.0     1100.0     1000.0      950.0      925.0
*** CARD TYPE 36 : GRU SOFTWOOD PROPORTION OF VOLUME PER ACRE BY MI BY AC
40110000  36 1              .90
40110000  36 2              .93
40110000  36 3              .93
40110000  36 4              .97
40110000  36 5             1.00
```

Figure 12–Detailed data GRU file (continued).

The run header and ACU data are presented in figure 13. Little has changed from the minimum data requirement here except card 05 has been added to request a more detailed set of output.



```
** HEADER FILE FOR DETAILED EXAMPLE
*** CARD TYPE 01 : RUN HEADER
01                  MANAGEMENT INTENSIFICATION
*** CARD TYPE 02 : TIME INFORMATION
02                        1983        10         3    1.299
*** CARD TYPE 03 : AGE CLASS REPORT GROUPS
03  0                        1
03  1                        1
03  2                        2
03  3                        2
03  4                        3
03  5                        3
03  6                        4
03  7                        4
03  8                        5
03  9                        5
03 10                        6
03 11                        6
03 12                        7
03 13                        7
03 14                        8
03 15                        8
03 16                        8
03 17                        8
*** CARD TYPE 05 : REPORT MATRIX
05  2  ACU                   1         1         0         1         1         1
05  3  ACU SUM               1         1         0         1         1         1
*** CARD TYPE A1 : ACU NAME
A101                    DOUGLAS-FIR
*** CARD TYPE A2 : GRUS BELONGING TO ACU
A201                  40110000
*** CARD TYPE A3 : ACU HARVEST VOLUME BY PERIOD
A301  1   00              1.2012E+9      1.3858E+9      1.2332E+9      1.2087E+9
*** CARD TYPE A5 : ACU TREATMENT NAMES
A501  1               REGULAR STOCK
A501  2               GENETIC STOCK
A501  3                  CONVERSION
A501  4                PRECOMM THIN
A501  5               FERTILIZATION
A501  6                   COMM THIN
A501  7               FINAL HARVEST
*** CARD TYPE A6 : ACU MANAGEMENT INTENSITY NAMES
A601  1                MGNT PRESENT
A601  2                   MGNT-THIN
A601  3                    MGNT-TRT
A601  4               MGNT-GEN-THIN
A601  5                MGNT-GEN-TRT
*** CARD TYPE A7 : ACU SITE NAMES
A701  1                AVE SITE 175
A701  2                AVE SITE 140
A701  3                AVE SITE  87
*** CARD TYPE A8 : ACU SPECIES NAMES
A801  1                 DOUGLAS-FIR             1
```

Figure 13—Detailed data ACU file.

The final set of output, figure 14, represents a sample of each level of output from the TRIM results.

```
ACU     1          DOUGLAS-FIR                                  RUN  87/05/21. 11.47.46. PAGE    3            INVENTORY
          ALL GRU'S                                             RAF  87/05/21. 11.47.32.

                          MANAGEMENT INTENSIFICATION


                                  INVENTORY       CUBIC FEET REPORT  YEAR   1983
                                    SPECIES     ALL SPECIES
                                       SITE      ALL SITES
INVENTORY

 MANAGEMENT            S   AGE  DIA.       TOTAL        NET   GROWING   STOCK   VOLUME           GROWTH VOLUME ON NET GROWING STOCK
 INTENSITY             L  CLASS WTAV        AREA    SOFTWOOD      HARDWOOD       COMBINED      SOFTWOOD      HARDWOOD      COMBINED
1    MGNT PRESENT   1

                           0- 1   .5     183846.     1794746.      199416.       1994162.       652448.        72494.       724942.
                           2- 3  8.3     231204.   722421393.    80269044.     802690436.
                           4- 5 13.0      79865.   490403837.    54489315.     544893152.    618929418.     68769935.    687699353.
                           6- 7 19.3       5704.   114364836.    12707204.     127072040.     11928034.      1325337.     13253371.
                          TOTAL  6.3     500619.  1328984812.   147664979.    1476649791.    631509899.     70167767.    701677666.
1    MGNT PRESENT   2

                           2- 3  9.9      87521.   202467457.    22496384.     224963841.
                           4- 5 13.2      63962.   235047661.    26116407.     261164068.    255751048.     28416783.    284167831.
                           6- 7 17.2      15856.   132139737.    14682193.     146821930.     39107970.      4345330.     43453300.
                           8- 9 22.7      11679.   111308737.    12367637.     123676374.
                          10-11   .0          0.                                              9749735.      1083304.     10833039.
                          TOTAL 12.6     179017.   680963592.    75662621.     756626213.    304608753.     33845417.    338454170.
1    MGNT PRESENT   3

                           0- 1   .0      32289.                                                18534.         2059.        20594.
                           4- 5 14.4      17061.    15868230.     1763137.      17631366.      7184618.       798291.      7982908.
                           6- 7 18.7      70931.   290297984.    32255332.     322553315.     30591618.      3399069.     33990687.
                           8- 9 21.1       6323.    22057062.     2450785.      24507846.     54681627.      6075736.     60757363.
                          10-11 24.3       9181.    13083903.     1453767.      14537670.      5195409.       577268.      5772676.
                          TOTAL 14.2     135786.   341307178.    37923020.     379230198.     97671805.     10852423.    108524228.
1    MGNT PRESENT ALL

                           0- 1   .4     216135.     1794746.      199416.       1994162.       670982.        74554.       745536.
                           2- 3  8.8     318725.   924888850.   102765428.    1027654278.
                           4- 5 13.2     160888.   741319727.    82368859.     823688586.    881865083.     97985009.    979850092.
                           6- 7 18.4      92490.   536802557.    59644729.     596447285.     81627621.      9069736.     90697357.
                           8- 9 22.1      18002.   133365798.    14818422.     148184220.     54681627.      6075736.     60757363.
                          10-11 24.3       9181.    13083903.     1453767.      14537670.     14945144.      1660572.     16605715.
                          TOTAL  9.0     815421.  2351255582.   261250620.    2612506202.   1033790457.    114865606.   1148656064.
2       MGNT-THIN ALL

                           0- 1   .5      90551.      913445.       68754.        982199.       332067.        24994.       357061.
                           2- 3  9.4     113877.   367680142.    27674849.     395354991.
                          TOTAL  5.5     204428.   368593587.    27743603.     396337190.       332067.        24994.       357061.
6     ALL MI'S    ALL

                           0- 1   .5     306686.     2708191.      268170.       2976361.      1003049.        99548.      1102597.
                           2- 3  8.9     432602.  1292568992.   130440277.    1423009269.
                           4- 5 13.2     160888.   741319727.    82368859.     823688586.    881865083.     97985009.    979850092.
                           6- 7 18.4      92490.   536802557.    59644729.     596447285.     81627621.      9069736.     90697357.
                           8- 9 22.1      18002.   133365798.    14818422.     148184220.     54681627.      6075736.     60757363.
                          10-11 24.3       9181.    13083903.     1453767.      14537670.     14945144.      1660572.     16605715.
                          TOTAL  8.3    1019848.  2719849169.   288994224.    3008843392.   1034122524.    114890601.   1149013125.
```

Figure 14—Detailed summary output.

```
ACU    1           DOUGLAS-FIR                                                      RUN  87/05/21. 11.47.46. PAGE    4          HARVEST
           ALL GRU'S                                                                RAF  87/05/21. 11.47.32.
                                MANAGEMENT INTENSIFICATION

                                           HARVEST      CUBIC FEET REPORT  YEAR    1983 TO    1993
                                           SPECIES    ALL SPECIES
                                              SITE     ALL SITES
HARVEST

 MANAGEMENT             AGE  DIA.          HARVEST  FINAL HARVEST        COMM THIN       MORT. SALV      CONVERSION           TOTAL
 INTENSITY             CLASS WTAV           AREA          VOLUME            VOLUME           VOLUME          VOLUME          VOLUME
1    MGNT PRESENT
      SOFTWOOD
                        4- 5 15.2           8696.      59912816.                                                         59912816.
                        6- 7 18.4          66498.     395432251.                                                        395432251.
                        8- 9 21.3          61059.     408888706.                        47043209.                       455931915.
                       10-11 25.0          20860.     139337784.                        16846067.                       156183851.
                       TOTAL 20.2         157113.    1003571557.                        63889277.                      1067460834.
1    MGNT PRESENT
      HARDWOOD
                        4- 5 15.2           8696.        6656980.                                                         6656980.
                        6- 7 18.4          66498.       43936917.                                                        43936917.
                        8- 9 21.3          61059.       45432078.                        5227023.                        50659102.
                       10-11 25.0          20860.       15481976.                        1871785.                        17353761.
                       TOTAL 20.2         157113.      111507951.                        7098809.                       118606759.
1    MGNT PRESENT
      COMBINED
                        4- 5 15.2           8696.       66569795.                                                        66569795.
                        6- 7 18.4          66498.      439369168.                                                       439369168.
                        8- 9 21.3          61059.      454320784.                       52270233.                       506591017.
                       10-11 25.0          20860.      154819760.                       18717853.                       173537613.
                       TOTAL 20.2         157113.     1115079508.                       70988085.                      1186067593.

2          MGNT-THIN
      SOFTWOOD
                        2- 3    .0             0.                        54538560.                                       54538560.
                        4- 5    .0             0.                        79200606.                                       79200606.
                       TOTAL    .0             0.                       133739166.                                      133739166.
2          MGNT-THIN
      HARDWOOD
                        2- 3    .0             0.                         4105053.                                        4105053.
                        4- 5    .0             0.                         5961336.                                        5961336.
                       TOTAL    .0             0.                        10066389.                                       10066389.
2          MGNT-THIN
      COMBINED
                        2- 3    .0             0.                        58643613.                                       58643613.
                        4- 5    .0             0.                        85161942.                                       85161942.
                       TOTAL    .0             0.                       143805555.                                      143805555.

6    ALL MI'S
      SOFTWOOD
                        2- 3    .0             0.                        54538560.                                       54538560.
                        4- 5 15.2           8696.      59912816.         79200606.                                      139113422.
                        6- 7 18.4          66498.     395432251.                                                        395432251.
                        8- 9 21.3          61059.     408888706.                        47043209.                       455931915.
                       10-11 25.0          20860.     139337784.                        16846067.                       156183851.
                       TOTAL 20.2         157113.    1003571557.        133739166.      63889277.                      1201200000.
```

Figure 14--Detailed summary output (continued).

```
ACU         1     DOUGLAS-FIR                                                 RUN  87/05/21. 11.47.46. PAGE   29     SUMMARY REPORTS
                                                                              RAF  87/05/21. 11.47.32.
                            MANAGEMENT INTENSIFICATION

                                                 SUMMARY REPORT
                                                 ALL SPECIES
                                                 ALL SITES
INVENTORY-    CUBIC  FEET

     YEAR               TOTAL                NET  GROWING  STOCK  VOLUME               GROWTH VOLUME ON NET GROWING STOCK
                        AREA      SOFTWOOD            HARDWOOD          COMBINED      SOFTWOOD          HARDWOOD          COMBINED
     1983             1019848.  2719849169.        288994224.      3008843392.     1034122524.      114890601.      1149013125.
     1993             1019848.  2615676455.        282212996.      2897889451.     1416223403.      142854102.      1559077506.
     2003             1019848.  2646099858.        276369330.      2922469188.     1236047677.      122251367.      1358299045.
     2013             1019848.  2648947535.        273976657.      2922924192.     1065038998.      105146071.      1170185069.
REGENERATION

     YEAR               TOTAL      UNSTOCKED  FINAL HARVEST  REGENERATION      UNSTOCKED
                        AREA      AREA START           AREA          AREA     AREA ENDING
     1983             1019848.        10466.        157113.                        10466.
     1993             1019848.        10466.        147583.        157113.         10466.
     2003             1019848.        10466.        102278.        147583.         10466.
     2013             1019848.        10466.         87172.        102278.         10466.
TREATMENT

     YEAR               TOTAL    PRECOMM THIN     COMM THIN  FERTILIZATION      CONVERSION
                        AREA           AREA          AREA           AREA            AREA
     1983             1019848.       115740.       113877.
     1993             1019848.       190946.        89681.
     2003             1019848.       157113.        90551.
     2013             1019848.       147583.        70425.
HARVEST-    CUBIC  FEET     SOFTWOOD

     YEAR               TOTAL    MORTAL SALV     CONVERSION       COMM THIN  FINAL HARVEST         TOTAL        REQUESTED
                        AREA          VOLUME         VOLUME          VOLUME         VOLUME         VOLUME           VOLUME
     1983              157113.     63889277.                     133739166.    1003571557.    1201200000.      1201200000.
     1993              147583.                                   105817949.    1279982051.    1385800000.      1385800000.
     2003              102278.                                   103945605.    1129254395.    1233200000.      1233200000.
     2013               87172.                                    85603396.    1123096604.    1208700000.      1208700000.
HARVEST-    CUBIC  FEET     HARDWOOD

     YEAR               TOTAL    MORTAL SALV     CONVERSION       COMM THIN  FINAL HARVEST         TOTAL        REQUESTED
                        AREA          VOLUME         VOLUME          VOLUME         VOLUME         VOLUME           VOLUME
     1983              157113.      7098809.                      10066389.     111507951.     128673148.
     1993              147583.                                     7964792.     140732977.     148697769.
     2003              102278.                                     7823863.     116820177.     124644040.
     2013               87172.                                     6443266.     115639849.     122083116.
HARVEST-    CUBIC  FEET     COMBINED

     YEAR               TOTAL    MORTAL SALV     CONVERSION       COMM THIN  FINAL HARVEST         TOTAL        REQUESTED
                        AREA          VOLUME         VOLUME          VOLUME         VOLUME         VOLUME           VOLUME
     1983              157113.     70988085.                     143805555.    1115079508.    1329873148.
     1993              147583.                                   113782740.    1420715028.    1534497769.
     2003              102278.                                   111769467.    1246074573.    1357844040.
     2013               87172.                                    92046662.    1238736454.    1330783116.
```

Figure 14–Detailed summary output (continued).

```
ACU    1          DOUGLAS-FIR                                             RUN  87/05/21. 11.47.46. PAGE     5             HARVEST
          ALL GRU'S                                                       RAF  87/05/21. 11.47.32.

6     ALL MI'S
      HARDWOOD
                      2- 3   .0             0.                      4105053.                                      4105053.
                      4- 5 15.2          8696.       6656980.       5961336.                                     12618315.
                      6- 7 18.4         66498.      43936917.                                                    43936917.
                      8- 9 21.3         61059.      45432078.                      5227023.                      50659102.
                     10-11 25.0         20860.      15481976.                      1871785.                      17353761.
                     TOTAL 20.2        157113.     111507951.      10066389.       7098809.                     128673148.
6     ALL MI'S
      COMBINED
                      2- 3   .0             0.                     58643613.                                     58643613.
                      4- 5 15.2          8696.      66569795.      85161942.                                    151731737.
                      6- 7 18.4         66498.     439369168.                                                   439369168.
                      8- 9 21.3         61059.     454320784.                     52270233.                     506591017.
                     10-11 25.0         20860.     154819760.                     18717853.                     173537613.
                     TOTAL 20.2        157113.    1115079508.     143805555.      70988085.                    1329873148.
```

Figure 14--Detailed summary output (continued).

```
ACU         1     DOUGLAS-FIR                                             RUN  87/05/21. 11.47.46. PAGE   30   SUMMARY REPORTS
                                                                          RAF  87/05/21. 11.47.32.

ECONOMIC

     YEAR         REGENERATION   PRECOMM THIN  FERTILIZATION      COMM THIN      MORT SALV  FINAL HARVEST          TOTAL
                   NET REVENUE    NET REVENUE    NET REVENUE    NET REVENUE    NET REVENUE    NET REVENUE    NET REVENUE
     1983                              -8911957.                     308370165.                   3101036111.    3400494319.
     1993           -18445098.     -15142026.                     251490724.                   4070342923.    4288246524.
     2003           -17842757.     -12836154.                     253369666.                   3703954417.    3926645172.
     2013           -12743795.     -12417614.                     216626268.                   3683756862.    3875221721.

LAND SHIFT

     YEAR           MI 1  AREA     MI 2  AREA     MI 3  AREA     MI 4  AREA     MI 5  AREA  DONOR 1  AREA  DONOR 2  AREA
                  MGNT PRESENT      MGNT-THIN       MGNT-TRT  MGNT-GEN-THIN   MGNT-GEN-TRT
     1983              815421.        204428.
     1993              797353.        222496.
     2003              764661.        255188.
     2013              764661.        255188.
```

Figure 14--Detailed summary output (continued).

Tedder, P. L.; La Mont, Richard N.; Kincaid, Jonna C. 1987. The timber resource inventory model (TRIM): a projection model for timber supply and policy analysis. Gen. Tech. Rep. PNW-GTR-202. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 82 p.

TRIM (Timber Resource Inventory Model) is a yield table projection system developed for timber supply projections and policy analysis. TRIM simulates timber growth, inventories, management and area changes, and removals over the projection period. Programs in the TRIM system, card-by-card descriptions of required inputs, table formats, and sample results are presented. The programs are available from the Pacific Northwest Research Station.

Keywords: Computer programs/programing, models, timber inventory, timber supply, projections (supply/demand), simulation.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Report
PNW-GTR-203

Ponderosa Pine Managed-Yield Simulator: PPSIM Users Guide

Donald J. DeMars and James W. Barrett

Authors

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Abstract

DeMars, Donald J.; Barrett, James W. 1987. Ponderosa pine managed-yield simulator: PPSIM users guide. Gen. Tech. Rep. PNW-GTR-203. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 36 p.

PPSIM simulates yields of natural and managed ponderosa pine stands. Management practices and effects that can be simulated include commercial thinning, fertilization, genetic improvement, and presence of dwarf mistletoe. An option is available that adjusts growth to simulate local conditions. Equations used in PPSIM describe growth of natural stands, estimate the volume increment of thinned stands, and predict the amount and timing of mortality in natural stands. The Fortran IV program is available from the authors on request.

Keywords: Simulation, computer programs/programing, yield (forest), ponderosa pine, *Pinus ponderosa.*

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Introduction

In Oregon and Washington, management of the ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forest has intensified in the last 20 years; precommercial thinnings, commercial thinnings, and sanitation cuts are being done regularly on existing natural stands. The demand for information on growth of managed stands has increased in proportion to the increased management activity. The information is needed to estimate how growth of a stand responds to different management prescriptions so managers can compare estimated responses before treatments are applied.

The demand for information on growth led to the development of a computer simulation program, PPSIM, that estimates volume growth of natural and managed stands of ponderosa pine in eastern Oregon and Washington. PPSIM is an even-aged stand model that calculates the yearly growth of stands, sums yearly growth estimates to obtain total yield for each year, and reports yield totals per acre for specified report ages. (Report ages are the ages that appear in output tables produced by the simulation model.) The model allows a user to simulate commercial thinnings, simulate application of fertilizer, adjust growth (either positive or negative), estimate the impact of dwarf mistletoe (*Arceuthobium campylopodum* Engelm.) on volume growth, and vary rotation length.

Stand statistics reported are site index (Barrett 1978), total age of stand, height of tallest trees, quadratic mean diameter, basal area per acre, trees per acre, and gross cubic-foot volume per acre. Appropriate deductions need to be made for roads, nonforested areas, and defects that might be present in stands when these growth estimates are applied to a forest.

The growth equations and assumptions that determine yield in the program may need revision as more growth information becomes available. PPSIM should be used with caution because it was developed from limited data, and yields estimated by the model usually involve interpolation or extrapolation from the data base. These interpolations and extrapolations seem reasonable to us, but they have not been tested against actual yields of stands thinned regularly for 60 or 70 years. In the Pacific Northwest, such stand data do not exist.

PPSIM is similar to the program DFIT (Bruce and others 1977, Reukema and Bruce 1977) in program structure and depends heavily on natural-stand data and managed-stand growth assumptions. This is mentioned to give users familiar with DFIT insight into the uses and limitations of PPSIM. There are some differences in structure between the programs, however; the differences will be discussed in this paper.

PPSIM is written in Fortran IV and is available on the UNIVAC computer at the USDA Forest Service computer center in Fort Collins, Colorado. Copies of the program can be obtained from the authors or from Biometrics, Pacific Northwest Research Station, P.O. Box 3890, Portland, Oregon 97208.

Data Base

We used four data sources to establish regression equations for the simulation model:

1. Natural-stand data collected in the 1930's (Meyer 1961).
2. Remeasured plot data from managed stands of ponderosa pine collected by personnel from the Silviculture Laboratory, Bend, Oregon.
3. Temporary plot data from thinned stands; data were collected in 1973 and 1974 to supplement remeasured plot data.

4. Remeasured plot data from stands infested with dwarf mistletoe; data were collected by personnel from the Forestry Sciences Laboratory, Corvallis, Oregon.

The natural-stand data base contains 432 plots from even-aged stands of normal stocking (Meyer 1961). We used Barrett's site-index equation (Barrett 1978) to calculate a new site-index value for each plot. This update of natural-stand data to current site curves placed site indices for natural and managed stands on a common basis. Site-index ranges from 46 to 184 feet; stand age ranges from 25 to 182 years; square feet per acre of basal area ranges from 77 to 369; and the number of trees per acre ranges from 58 to 9,470. Plot locations are widely distributed in Washington, Oregon, and northern California.

For managed stands, the data base consists of 151 plots (105 permanent and 46 temporary) with 429 growth periods. All managed-stand plots are in Oregon and Washington, and about one-third of the plots contain some trees infected with dwarf mistletoe. The site-index range for managed-stand data is 33 to 139 feet, and stand age at the beginning of growth periods ranges from 15 to 93 years. Basal area ranges from 1.5 to 194 square feet per acre, and the range in number of trees per acre is 36 to 1,000.

Deficiencies in managed-stand data dictated the design of the simulation model. The small number of plot locations and treatments, the short timespan of observation after treatment, the geographic distribution of permanent plots, and the limited ranges of stand age and site index all contributed to the model's heavy dependence on natural-stand growth relationships and managed-stand growth assumptions.

Required Program Input

PPSIM is similar to DFIT in program structure, growth assumptions, and table outputs. PPSIM is more flexible, however, because a user has more input options to schedule and control thinnings and to adjust yearly growth of stands.

Formats for 13 input records are given in appendix 2. Record 1 is the master control record, and input variables of this record control either some aspect of computer output or the reading of optional input records. A master control record must be read for each natural- or managed-stand table produced. Few variables on the master control record and optional input records are needed at any one time to produce a table because many of the variables perform similar functions in controlling output. Specifying the value of one variable might eliminate the need for or even preclude the use of another. Enough variables must be specified, though, to define site index, first report age, a schedule of report ages, and harvest age.

Site Index

Site index is specified either in columns 1 to 3 of the master control record or in columns 1 to 4 of the starting stand-statistics record (input record 13). If site index is not specified, the program calculates site index using Barrett's (1978) site-index equation and the variables for stand height (STHT) and breast-height age (STAGE) from the starting stand-statistics record.

First Report Age

Many variables can be used to set the first report age. These variables are listed in table 1 along with their input record number, input columns, and program variable name. A user commonly specifies only one or two variables from table 1. Often, one diameter variable is specified along with one age variable. Diameter variables are interrelated, and only one is needed to set the values of the others. If more than one diameter is specified, the model assumes a hierarchical arrangement of (1) minimum

Table 1—Variables that can set first report age

Variable description	Variable name	Record number	Input columns
Minimum DBH (outside bark) of a merchantable tree	DQMM	1	4-7
Average DBH (outside bark) stand has to attain before a commercial thinning is allowed	DQTP	1	8-11
Average DBH (outside bark) the merchantable part of stand has to attain before a commercial thinning is allowed	DQMP	1	12-15
Total age of stand at first report age	AGETF[1]	1	16-18
Breast height age of stand at first report age	AGEBHF	1	19-21
Total age of stand at first report age	AGETOT(1)[1]	2	1-3
Total age of an existing stand	STTAGE	13	9-12
Breast height age of an existing stand	STAGE	13	13-16

[1] AGETF and AGETOT(1) could have the same numerical value. Usually, only one of the input variables is specified per output table. If AGETF is specified and AGETOT(1) is not, then AGETF, along with some other input variables, will determine the value of AGETOT(1).

DBH (diameter at breast height, outside bark) of a merchantable tree, (2) average DBH (outside bark) of a stand at the first possible commercial thinning, and (3) average DBH (outside bark) that the merchantable part of stand has to attain before a commercial thinning will occur. Under this hierarchy, the first diameter is used to calculate values for the second and third diameters; these calculated diameters override any values set by the user. When only the second and third diameters are specified, the second diameter is used to calculate values for the first and third diameters. If the first and second diameters are not specified, the third diameter must be given.

Diameters have a dual function in the simulation model. First, diameters are used in the calculation of first report age. Total age of a natural stand at the first possible commercial thinning is calculated using the specified or calculated DBH (outside bark) of the average tree in the stand, site index, and a natural-stand equation that relates total stand age to site index and average stand DBH. This calculated total age is compared with other specified ages in table 1 to determine first report age. Note that ages read from the starting stand-statistics record override all other ages (calculated or specified) in determining the first report age. Second, diameter variables set the minimum average diameter that a stand must attain before a commercial thinning is allowed. A scheduled thinning will not occur if the average DBH (outside bark) of the stand is below the minimum average stand diameter needed for commercial thinning.

Schedule of Report Ages

In PPSIM, report ages for natural and managed stands are set by one or more of the following variables: (1) total age of stand, (2) height of tallest trees in the stand, (3) basal area of the stand, and (4) stand-density index (Reineke 1933). These variables can be used separately or in combination.

Total age of the stand is used to schedule report ages in most tables. Desired ages either are specified on input record 2 or are calculated using the first thinning or report age and the variables for "report-age interval" and "number of report ages" from the master control record.

When height of the tallest trees in a stand is used to determine report ages, a set of ascending-ordered heights must be specified on input record 3. If record 3 is not used, then an ascending-ordered height set is calculated using the initial height of the stand at the first report or thinning age and the variables for "height interval" and "number of report ages" from the master control record. First report age is set to the age at which stand height exceeded the first height of the ordered set. Successive ages are set as the stand grows and stand height exceeds subsequent target heights.

If basal area of the stand is used to determine report ages, the target basal area must be specified on the master control record (columns 31-34), or a set of target basal areas must be read from input record 4. The first report age is set to the age when stand basal area exceeds the first target basal area specified. Successive ages are set as the stand grows and stand basal area exceeds subsequent target basal areas.

When stand density is used to determine report ages, a set of target stand-density indices is specified on input record 6. The model calculates stand-density index after each yearly growth projection, and the first report age occurs when calculated stand-density index exceeds the first target stand-density index specified. Successive ages are set when the yearly calculated stand-density index exceeds subsequent specified stand-density indices.

Most of the time, variables that determine report ages are not used in conjunction with one another; however, the model does allow this option. Total age is dominant when used with any of the other three variables; report ages are determined by the specified set of total ages, and the three subordinate variables cannot influence this schedule. Subordinate variables do, however, become constraints when thinnings are scheduled. A thinning is delayed to a later specified age if, at the time of a scheduled thinning, stand values for subordinate variables do not exceed their target values.

If a combination of variables used to determine report ages contains only subordinate variables, then first report age will occur when all given subordinate variables exceed their first specified values. Successive ages are set in a similar manner.

Harvest Age

A harvest cut occurs when stand age equals the designated harvest age or when stand height exceeds a specified harvest height. Total stand age at harvest is either specified in columns 35 to 37 of the master control record or calculated by adding "final-age interval" to the last scheduled intermediate report age. A user may specify the "final-age interval" on the master control record (columns 38 to 40) or allow the model to set it equal to the "age interval" (columns 25 to 27 of the master control record).

Stand-harvest height is calculated by adding final-height interval to the last scheduled intermediate height. A user can specify "final-height interval" on the master control record (columns 41 to 43) or allow the model to set it equal to "height interval" (columns 28 to 30 of the master control record).

Optional Program Input

Managed- or Natural-Stand Option

The user designates in columns 77 and 78 of the master control record whether the simulation is for a natural or a managed stand. If the managed-stand option is selected, all scheduled report ages become potential commercial thinning ages. Whether a thinning occurs depends on the variables used to trigger report ages. For a full explanation of this subject, see the earlier section, "Schedule of Report Ages."

Average Diameter of Cut Trees in Thinning

A user can control, within limits, the size of trees cut during a commercial thinning. Quadratic mean diameter of cut trees can be set as a proportion of the quadratic mean diameter of all trees in a stand that exceed the minimum diameter limit of a merchantable tree. If this option is selected, the proportions (or ratios) entered on input record 9 should be in the numerical range of 0.9 to 1.1.

Stand After Thinning

If the user does not select one of the options to describe the stand after thinning, the simulation program calculates the basal area of the stand after thinning. This value is derived from equations describing recommended basal areas when site index and the quadratic mean diameter of the leave stand are given. A user can override calculated basal area values by supplying values after thinning for one of three optional input variables: (1) square feet per acre of basal area left after thinning (input record 5), (2) stand-density index of the leave stand (input record 7), or (3) trees per acre left after thinning (input record 8). Only one of these input records can be used per yield table.

Fertilization and Growth Adjustments

Yearly volume growth can be adjusted to simulate local growth conditions, fertilization, genetic improvement, and impact of diseases or insects. Adjustments to volume growth are translated into corresponding changes in diameter and height of the average tree. The model allows the user to specify up to 20 growth adjustments during the life of a stand. For each growth adjustment, the effective age, magnitude, and duration of the growth-rate change must be defined. Usually, values for these variables are set on input records 2, 10, and 11; however, the user can omit these input records and let the model supply default values.

Thinning and report ages become growth-adjustment ages when input record 10 is omitted and a "YES" is specified in columns 58 to 60 on the master control record. If adjustment percentages are called for but not supplied by the user on input record 11, the model assumes the stand will be fertilized and calculates the percentage of change in growth using the fertilizer equation. All growth changes are assumed to last 5 years, but the user can override this adjustment period by supplying an alternate period length on input record 2 or input record 10. If more than one growth adjustment is scheduled within an adjustment period, a cumulative effect on growth is assumed. The cumulative effect is limited, however, to only the two most recent growth adjustments in an adjustment period.

Growth adjustments are usually applied to thinned stands, but PPSIM allows the user to change the growth rate of natural stands when desired. This feature should be used with caution because the effect of a growth-rate change on natural-stand tree mortality is unknown. The model does change the rate of tree mortality when the growth rate is changed, but the accuracy of this change has not been tested.

Dwarf Mistletoe Option

Several program input variables pertain to dwarf mistletoe infestations in ponderosa pine stands. On the master control record, the user can set the number of trees per acre infected with dwarf mistletoe and the age of the stand when this infestation level is observed. The model projects the development of the infested stand, starting at the observation age, by estimating the yearly volume growth of the stand and the yearly increases in the number of trees in the stand infected with dwarf mistletoe. Impact of dwarf mistletoe on yearly volume growth is represented in the managed-stand volume-growth equation as a function of the number of infected trees per acre. Intensification of dwarf mistletoe within the stand is estimated by an equation that relates yearly increase in the number of infected trees to the total number of trees per acre and the current number of infected trees per acre.

The number of infected trees per acre left after a thinning can be set on input record 12. If the user does not supply values after thinning, the model assumes that the leave stand has the same percentage of infected trees to healthy trees as the stand had before thinning.

To estimate the impact of dwarf mistletoe on cubic-foot volume growth over a rotation, two computer tables must be produced. One table shows the growth and yield estimates of a healthy stand for a given set of input variables, and the second table simulates the growth and yield of a stand infested with dwarf mistletoe when the identical set of input values that produced the healthy-stand table is given. The impact on volume growth over a rotation is estimated by subtracting results for stands infested with dwarf mistletoe from results for healthy stands.

The model cannot estimate the effect of dwarf mistletoe on natural-stand growth; however, the user can adjust volume growth of natural stands by a specified percentage (usually negative) to simulate the impact of dwarf mistletoe. Because the effects of dwarf mistletoe on tree mortality in natural stands are unknown, caution should be used if this option is selected.

The adjustment option for percentage of growth can also be used for managed, infested stands when estimates of the dwarf mistletoe impact calculated by the program do not appear accurate for a particular geographic area.

For sapling stands, Barrett and Roth (1985) report no significant difference in volume growth between managed, healthy stands and managed, dwarf mistletoe-infested stands. According to Barrett and Roth (1985), "Results indicate that parasitized ponderosa pine saplings can be managed by wide spacing that increases tree height growth in spite of abundant dwarf mistletoe. As long as rapid increase in height continues, this treatment will produce trees with healthy crowns and an acceptable rate of growth." If this is thought to occur, then table results for healthy stands should be used to estimate volume growth for managed, infested stands.

Projecting the Growth of an Existing Stand

An option is available in PPSIM that allows a user to enter stand statistics for an existing stand and project the growth of that stand to harvest cut under selected management treatments. To exercise this option, a "YES" is entered in columns 65 to 67 of the master control record, and starting stand statistics are set on input record 13. The format for input record 13 and other pertinent information about this option are given in appendix 2.

Only three types of stands can be entered and projected using this option:

1. Understocked stands.
2. Recently thinned stands.
3. Fully stocked stands (similar to natural stands) scheduled for immediate thinning.

PPSIM assumes that basal area per acre of an existing stand is either comparable to a thinned stand or will be thinned before projection of stand growth proceeds. The growth routine for thinned stands is used in volume-growth projections of existing stands. The present version of PPSIM cannot project the growth of juvenile stands (that is, stands less than 20 years of age).

Function List

Equations that control PPSIM estimates appear in individual function routines at the end of the simulation program. This program design was chosen to eliminate repetition of complex equations and to facilitate future revision. Most equations are derived from data by using regression analysis techniques. A few equations are based on assumptions we formulated after reviewing the literature. One equation is based on stocking guidelines now in use in Oregon and Washington. Changes in some equations can be made without regard to other equations; changes in others imply or require changes in companion equations. The variable names listed and defined in appendix 1 and used in the following explanations of function routines are not the same as those used in the computer program. For the manuscript, variable names were shortened and made consistent from one function routine to the next. Variable names used in the function routines of the computer program must be used when equations are changed in the program.

Natural-Stand Functions

Function routine (1-10) calculates breast-height (b.h.) age (AB) of a natural stand given Barretts's (1978) site index (SIB) and total stand age (AT):

$$AB = AT - 23.84 + 0.109 * SIB \,. \qquad (1\text{-}10)$$

A change in this equation requires a change in the equation for function routine (1-20).

Function routine (1-20) calculates total age (AT) of a natural stand given Barrett's site index (SIB) and b.h. age (AB):

$$AT = AB + 23.84 - 0.109 * SIB \,. \qquad (1\text{-}20)$$

A change in this equation requires a change in the equation for function routine (1-10).

Function routine (1-30) estimates quadratic mean diameter (DG) of a natural stand given b.h. age (AB) and Barrett's site index (SIB):

$$\begin{aligned} DG = 10.0 ** [&1.498 + 0.0007547 * AB^{1.1} \\ &+ 1037620.0 / SIB^4 - 521.675 / (SIB * AB^{0.5})] \,. \end{aligned} \qquad (1\text{-}30)$$

Equations of function routines (1-30), (1-40), (1-50), and (1-60) are derived from the same data, and this group of equations must be kept consistent. A change in the data used to develop these equations or a change in any of the equations will necessitate changes in all these function routines.

Function routine (1-40) calculates b.h. age (AB) of a natural stand given quadratic mean diameter (DG) and Barrett's site index (SIB). In this routine, an iterative procedure is used to solve the equation of function routine (1-30) for b.h. age. This iterative procedure is necessary because a direct algebraic expression for b.h. age cannot be obtained by rearrangement of equation variables.

Function routine (1-50) calculates trees per acre (N) in a natural stand given Barrett's site index (SIB) and b.h. age (AB):

$$\begin{aligned} N= 10.0 ** [&1.952 - 0.002467 * AB^{1.1} \\ &- 410829.0 / SIB^{4} + 786.595 / (SIB * AB^{0.5})] . \qquad (1\text{-}50) \end{aligned}$$

Function routine (1-60) calculates basal area per acre (G) of a natural stand given site index (SIB) and b.h. age (AB):

$$\begin{aligned} G= 10.0 ** [&2.6853 - 0.0009574 * AB^{1.1} \\ &+ 1664411.0 / SIB^{4} - 256.755 / (SIB * AB^{0.5})] . \qquad (1\text{-}60) \end{aligned}$$

This equation is derived by substituting the equations of function routines (1-30) and (1-50) into the algebraic relationship:

$$G = 0.005454154 * N * DG^{2} .$$

Function routine (1-70) estimates the average height (HT) (Barrett 1978) of the five tallest trees per acre in a stand given site index (SIB) and b.h. age (AB):

$$\begin{aligned} HT = 4.5 + \{&128.89 * [1.0\text{-}e ** (- 0.01696 * AB)] ** 1.231\} \\ &- \{ [- 0.7864 + 2.4972 * (1.0\text{-}e ** (- 0.004504 * AB)) ** 0.3302] * 100.43\} \\ &+ \{ [- 0.7864 + 2.4972 * (1.0\text{-}e ** (- 0.004504 * AB)) ** 0.3302] * (SIB\text{-}4.5)\} . \qquad (1\text{-}70) \end{aligned}$$

Equations of function routines (1-70) and (1-80) are derived from the same data, and a change in one requires a change in the other.

Function routine (1-80) estimates site index (SIB) (Barrett 1978) given b.h. age (AB) and average height (HT) of the five tallest trees per acre in the stand:

$$\begin{aligned} SIB = 4.5 + 100.93 - &(1.1986 - 0.002831 * AB + 8.444 / AB) \\ &* \{128.895 * [1.0 - e ** (- 0.01696 * AB)] ** 1.2314\} \\ &+ [(1.1986 - 0.002831 * AB + 8.444 / AB) * (HT - 4.5)] . \qquad (1\text{-}80) \end{aligned}$$

Function routines (1-70) and (1-80) are used for both natural and managed stands. The equations in these routines were developed using data from trees that grew primarily under natural-stand conditions. Height growth of the five tallest trees per acre in an even-aged natural stand is assumed to be unaffected by the reduction in stand density that occurs when a stand is thinned.

Function routine (1-90) calculates the ratio of volume to basal area (VGRT) of a natural stand given height (HT) of the five tallest trees per acre:

$$\mathrm{VGRT} = 10.0 ** [-0.3524 + 0.9062 * \mathrm{Log}(\mathrm{HT})] . \qquad (1\text{-}90)$$

This equation is derived from natural stand data in Meyer (1961) and is combined with results from function routines (1-60) and (1-70) to estimate cubic-foot volume per acre of natural stands. For managed stands, volume per acre of the total stand at first-thinning age is estimated from these function routines when the starting stand-statistics option is not used.

Stand-Component Functions

The stand attributes estimated by natural-stand function routines (1-10) through (1-60) and function routine (1-90) are based on all trees in the stand with a d.b.h. 0.6 inch or greater. PPSIM divides these total-stand estimates into merchantable, submerchantable, cut (if thinned), total leave, and mortality components (see computer-produced tables in appendix 3). To do this, the model uses equations that predict the diameter distribution of a stand, the ratio of stand volume to basal area, stand height-diameter-age relationships, and cubic-foot volumes for individual trees.

Function routine (2-10) calculates the percentage of trees in a stand smaller than a specified diameter class (DP) given the quadratic mean diameter of the total stand (DG) and the diameter class (Di):

$$\begin{aligned} \mathrm{DP} = {} & 1241.05 + 52.43 * \mathrm{DG} - 2509.7 * \mathrm{DG}^{0.25} - 956.67 * \mathrm{Di}^{0.25} \\ & - 156.0 * \mathrm{Di}^{0.75} + 264.15 * \mathrm{DG}^{0.5} * \mathrm{Di}^{0.5} \\ & + 2720.53 * \mathrm{DG}^{0.25} * \mathrm{Di}^{0.25} - 1646.07 * \mathrm{DG}^{0.5} * \mathrm{Di}^{0.25} \\ & - 0.006643 * \mathrm{DG}^{1.5} * \mathrm{Di}^{1.5} + 1060.81 * \mathrm{DG}^{0.5} . \qquad (2\text{-}10) \end{aligned}$$

With this equation, trees per acre and basal area per acre are calculated for each 1-inch diameter class in the stand. These estimates are made for every year the stand remains in a natural condition. The yearly 1-inch class values are used to divide the stand into its merchantable, submerchantable, and mortality components.

Mortality estimates calculated from the diameter distribution are somewhat biased because mortality of ingrowth trees is not included in the calculation. Data on ingrowth and ingrowth mortality are not available.

Function routine (2-20) estimates the height of the average tree in a stand component (HC) given the quadratic mean diameter of the trees in the component (DGC) and total age of the stand (AT):

$$\mathrm{HC} = -5.063 + 0.3542 * \mathrm{AT} + 3.047 * \mathrm{DGC} . \qquad (2\text{-}20)$$

Results from this equation are used as input for function routines (2-30) and (2-40). A change in this equation necessitates an equation change in function routine (2-30) but no change in function routine (2-40).

Function routine (2-30) estimates the ratio of volume to basal area for a stand component (VGRC) given the mean height of the trees that make up the component (HC):

$$VGRC = 10.0 ** [0.07407 + 0.7345 * \mathrm{Log}\,(HC)] . \tag{2-30}$$

VGRC is used for calculating volumes for the submerchantable and mortality components of a natural stand. Volume calculations for the cut and total leave components of a managed stand use results of function routines (2-20) and (2-40). Volume estimates for the total stand before thinning are calculated either from the natural-stand equations or from the managed-stand growth equation.

Function routine (2-40) calculates the cubic-foot volume of the component mean tree (VC) when total tree height and diameter breast height outside bark are given. Quadratic mean diameter (DGC) and average height of the trees in a stand component (HC) are the primary inputs for this function routine. Several equations make up this routine; the first is the weighting factor:

$$WT = (HC-2.25) / (HC-4.5) .$$

WT is used in the equation that calculates inside bark form factor (FI) for trees less than 20 feet tall:

$$\begin{aligned} FI = [&0.56042 + 0.29449 / (DGC * WT) - 12.7007 / HC^2 + 1.24786 / (DGC^2 * WT^2) \\ &- 0.05073 * HT / (DGC * WT)] * WT^2 . \end{aligned}$$

For trees 20 feet tall or taller, the inside-bark form factor (FI) is:

$$\begin{aligned} FI = (&0.7129 + 6.640 / HC - 0.760 / DGC - 1.615 * DGC / HC \\ &+ 1.697 * DGC^2 / HC^2) . \end{aligned}$$

Once the inside-bark form factor is estimated, double bark thickness at breast height (DB) is calculated as:

$$DB = 10.0 ** \{ - 0.8838 + 1.3977 * \mathrm{Log}\,(DGC) - 0.2917 * [\mathrm{Log}\,(DGC)]^2 \} .$$

The final calculation in function routine (2-40) uses FI, DB, DGC, and HC to estimate total cubic-foot volume (VC) of the "average" tree in the stand component:

$$VC = 0.005454154 * (DGC - DB)^2 * HC * FI . \tag{2 - 40}$$

The equations for FI and DB are derived from stem-analysis data collected by personnel from the Silviculture Laboratory in Bend, Oregon. A change in one of these equations requires a change in the other.

Thinning-Function Routines

Trees per acre and basal area per acre of the cut portion of a stand are obtained by subtracting values after thinning from values before thinning. Values for the leave stand are either set by the model or specified by the user on optional input records 5, 7, or 8. If the model sets the values for the leave stand, function routine (3-10) calculates trees per acre (TAR) and basal area per acre of the leave stand (GAR) given the quadratic mean diameter of the leave stand (DGC). Two equations and two sets of limits are used when these estimates are made. The number of recommended trees per acre (TAR) for stands with site indices less than 81 is calculated by the equation:

$$TAR = 10.0 ** [2.2217 - 0.4088 * Log (DGC)] .$$

TAR is not allowed to be less than 50 or greater than 125. For stand site indices of 81 or greater, the number of recommended trees per acre (TAR) is set by the equation:

$$TAR = 10.0 ** [3.8 - 1.7105 * Log (DGC)] .$$

In this case, TAR is not allowed to be less than 55 or greater than 250. Once TAR is estimated, the recommended basal area per acre (GAR) is calculated from the relationship:

$$GAR = (0.005454154 * DGC^2) * TAR . \qquad (3\text{-}10)$$

All equations in function routine (3-10) are obtained from stocking guidelines now in use in Oregon and Washington.

PPSIM permits the use of stand-density index to set report or thinning ages. When this option is used, the model calculates the density index of the stand after each growth year and compares this value with the specified stand-density index (input record 6). A thinning is scheduled whenever the density index of the stand exceeds the preset value. Function routine (3-20) estimates stand-density index (SDI) given the number of trees per acre (N) and the quadratic mean diameter (DG):

$$SDI = (\{365.38 * N\} / \{10.0 ** [4.3281 -1.7653 * Log (DG)] \}) . \qquad (3\text{-}20)$$

This equation was derived from the natural-stand data of Meyer (1961) and should be changed if other natural-stand equations are changed.

Stand-density index of the leave stand can be designated for each thinning on input record 7. Function routine (3-30) converts the specified density indexes (SDI) and the quadratic mean diameter (DG) of the leave stand into the number of trees per acre (N) left after thinning:

$$N = \{SDI / 365.38\} * \{10.0 ** [4.3281 -1.7653 * Log (DG)] \} . \qquad (3\text{-}30)$$

This equation is derived from the SDI equation and must be changed if function routine (3-20) is changed.

Volume Growth of Managed Stands

Function routine (4-10) estimates yearly cubic-foot volume growth of managed stands (CVM) given site index (SIB), basal area per acre (G), average height of tallest trees (HT), and number of trees per acre infected with dwarf mistletoe (NI):

$$CVM = (-1.7191 + 0.5873 * G + 0.4809 * SIB - 0.1219 * NI - 0.2267 * HT) . \qquad (4\text{-}10)$$

This is an empirical equation derived from managed-stand data by using regression techniques. We recommend that the equation be revised as additional managed-stand information becomes available. A revision is necessary because the volume equation is derived from a small number of sample plots characterized by a limited number of treatments, a limited geographic distribution, and limited data ranges for stand age and site index. Also, growth patterns after treatment are not completely represented because data used for equation development are from recently treated stands (thinnings were typically less than 15 years old). Treated stands need to be observed over longer periods so that changes in growth rate over time can be established.

Adjustments to managed-stand volume growth are specified on optional input record 11, or the user can allow the model to set adjustment percentages by specifying a fertilization option and omitting input record 11. Function routine (4-20) estimates the percentage of volume-growth adjustment for fertilization (PA) when the site index (SIB) of the stand is given:

$$PA = (200.0 - SIB) / 640.0 . \qquad (4\text{-}20)$$

This equation is based on four simple assumptions and was not derived from data on the response of ponderosa pine to fertilizer. Such data are not available. The four assumptions are:

1. The response of ponderosa pine to fertilization (200 pounds of nitrogen per acre) is a 25-percent increase in growth rate when site index is 40.

2. The response of ponderosa pine to fertilization is a zero-percent increase in growth rate when site index is 200 or greater.

3. The growth-rate response of ponderosa pine to fertilization is linearly related (negatively) to site index (see fig. 1).

4. The effects of a fertilizer treatment will last 5 years unless an alternative period is specified on input control records.

Any of the assumptions of function routine (4-20) can be changed without changing the other equations. Changes in assumptions 1 through 3 require a revision in the function routine; a change in assumption 4 requires a program change in the fertilizer section of the growth subroutine.

Dwarf Mistletoe Functions

In the managed-stand volume-growth equation, the impact of dwarf mistletoe is expressed as a function of the number of infected trees per acre. The initial number of infected trees in a stand and the age of the stand when this infestation level was observed are specified on the master control record by the user. When the growth of a managed, infested stand is projected, the number of infected trees increases over time and usually decreases with thinning.

The number of infected trees left after thinning is either specified on input record 12 or set by the model. If input record 12 is not used, the assumption is that the leave stand has the same ratio of infected trees to healthy trees as the stand had before thinning. Function routine (5-10) calculates the number of infected trees removed during a thinning (NIC) given the number of infected trees before thinning (NI), the total number of trees before thinning (N), and the number of trees cut (NC) (this includes submerchantable trees when present):

$$NIC = NI * NC / N . \qquad (5\text{-}10)$$

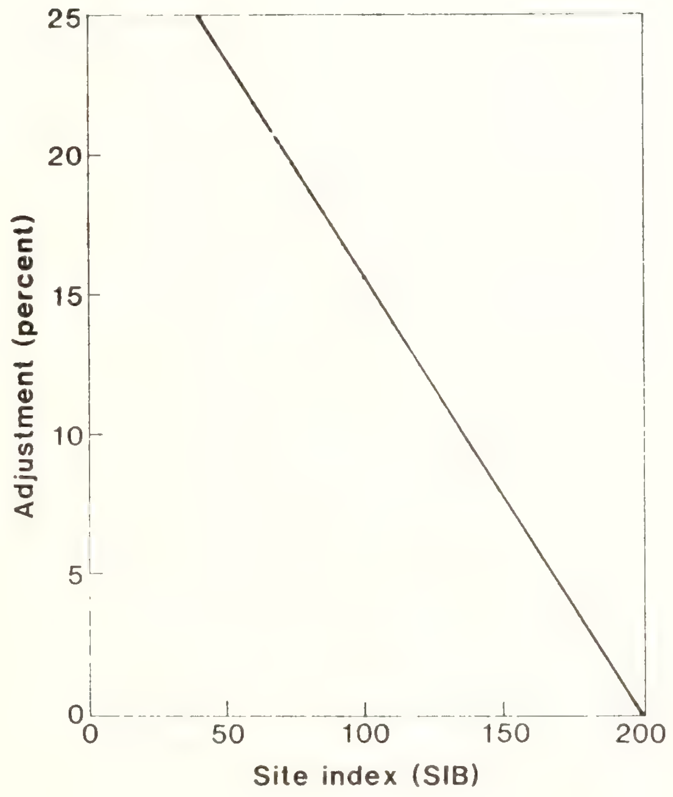

Figure 1—The percentage of fertilizer growth adjustment decreases as the site index increases.

Results from this equation are subtracted from the number of infected trees before thinning to obtain the number of infected trees after thinning.

Function routine (5-20) estimates the yearly increase in the number of infected trees (NIY) given the initial number of infected trees (NI) and total number of trees (N) in the stand:

$$NIY = 0.4574 + 0.07075 * NI - 6.573 * NI / N . \qquad (5\text{-}20)$$

This function was derived from limited data using regression analysis techniques. Unreasonable results occur with this equation when the number of infected trees approaches the total number of trees in the stand. As a control over this inconsistency, the model does not allow the number of infected trees to exceed the total number of trees in the stand.

Yield Tables

Samples of program input along with corresponding output tables are presented in appendix 3. Users adapting PPSIM to another computer can use this information to check for errors in program conversion. Numerical values presented in output tables are stated with sufficient digits to allow checks of consistency. The extra digits do not imply accuracy and should be ignored when comparisons among tables are made.

Although output tables are designed to be self explanatory, a few things about the tables need clarification. Site index (top of table) is defined as average height of the five tallest trees per acre at 100 years b.h. age. Stand height is also based on the five tallest trees per acre, and the height equation is conditioned to force stand height equal to site index at 100 years b.h. age. Program output shows that, at report age 100, stand-height estimates do not equal site index. The reason for the difference is that the ages shown in output tables are total ages and not b.h. ages.

For each report age in a natural-stand table, statistics are given for total stand and for submerchantable and merchantable components that make up the total stand. An estimate of tree mortality between report ages is also given. Mortality estimates are somewhat biased because ingrowth trees that enter the stand during the growth period and die are not included in the mortality estimates.

Unless a user specifies an existing stand on the starting stand-statistics input record, managed stands are of natural origin. Managed-stand tables are identical to natural-stand tables for report ages less than the age at first commercial thinning. Once a stand has been commercially thinned, the assumption is that only merchantable trees are left in the stand and that tree mortality will not occur.

Metric Equivalents

1 inch = 2.540 centimeters

1 foot = 0.3048 meter

1 square foot = 0.09290 square meter

1 cubic foot = 0.02832 cubic meter

1 square foot per acre = 0.2296 square meter per hectare

1 cubic foot per acre = 0.06997 cubic meter per hectare

1 acre = 0.4047 hectare

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Appendix 1: Variable Names

AB	Breast-height age of stand
AT	Total age of stand
CVM	Yearly cubic-foot volume growth of managed stands
DB	Double bark thickness
DG	Quadratic mean diameter of the average tree in the stand
DGC	Quadratic mean diameter of a stand component
Di	Diameter class
DP	Percentage of trees in the stand that are smaller than a given diameter class
e	Base of natural logarithms (2.718282)
FI	Tree form factor (inside bark)
G	Basal area per acre (square feet)
GAR	Recommended basal area per acre after commercial thinning
HC	Mean height of a stand component
HT	Height of the stand
N	Number of trees per acre
NC	Number of trees per acre cut during commercial thinning
NI	Number of trees per acre infected with dwarf mistletoe
NIC	Number of trees per acre infected with dwarf mistletoe cut during commercial thinning
NIY	Yearly increase in the number of trees per acre infected with dwarf mistletoe
PA	Percentage of volume-growth adjustment for fertilization
SDI	Stand-density index
SIB	Site index of the stand (Barrett 1978)
TAR	Recommended number of trees per acre after commercial thinning
VC	Cubic-foot volume of the average tree in a stand component
VGRT	Stand cubic-foot volume divided by stand basal area
VGRC	Cubic-foot volume divided by basal area of stand component
WT	Weighting factor for tree-volume equation

Appendix 2: Input Record Formats

Required Input Record

Master control record, input record 1—A master control record is required input for each natural- or managed-stand table produced. All other input records are optional and must be used in conjunction with the master control record. The format of the master control record is:

Input columns	Variable name	Variable description	Read format
1-3	SIB	Site index of stand (Barrett's site curves)	F3.0
4-7	DQMM	Minimum diameter of a merchantable tree	F4.2
8-11	DQTP	Quadratic mean diameter of stand at first commercial thinning	F4.2
12-15	DQMP	Quadratic mean diameter of the merchantable part of stand at the first commercial thinning	F4.2
16-18	AGETF	Total age of stand at first report age	F3.0
19-21	AGEBHF	Breast-height age of stand at first report age	F3.0
22-24	NCT	Number of report ages (or thinnings)	I3
25-27	TIY	Report-age interval (years)	F3.0
28-30	TIH	Height-growth interval between report ages	F3.0
31-34	GFMIN	Minimum stand basal area at commercial thinning	F4.0
35-37	HARAGE	Total age at harvest cut	F3.0
38-40	FIY	Number of years between final intermediate report age and harvest age (final age interval)	F3.0
41-43	FIH	Height-growth interval between final intermediate report age and harvest cut (final height interval)	F3.0
44-45	TAS	Number of report ages set on input record 2	I2
46-47	THS	Number of heights set on input record 3	I2
48-49	TGSB	Number of target basal areas set on input record 4	I2
50-51	TGSA	Number of after-thinning basal areas set on input record 5	I2
52-53	NSDIB	Number of minimum stand-density indices set on input record 6	I2
54-55	NSDIA	Number of after-thinning stand-density indices set on input record 7	I2
56-57	NTASP	Number of thinnings where number of leave trees per acre is set (input record 8)	I2
58-60	FCT	Fertilized at thinnings? (YES or blank)	A3
61-62	FAS	Number of growth-adjustment ages set on input record 10	I2
63-64	FPC	Number of growth-adjustment percentages set on input record 11	I2
65-67	SSS	Starting stand statistics set? (YES or blank)	A3
68-69	DRAT	Number of DCUT/DMERCH ratios set on input record 9	I2
70-72	SINFTA	Number of trees per acre infected with dwarf mistletoe	I3
73-74	SINAGE	Stand age at dwarf mistletoe infestation	I2
75-76	NINFSP	Number of thinnings where number of leave trees per acre infected with dwarf mistletoe is specified (input record 12)	I2
77-78	NSTAB	Type of stand table (1 = natural, blank = managed)	I2
79-80		Input record identification (optional)	

Optional Input Records

Report-age option, input record 2—The number of report ages entered on input record 2 is set by the variable TAS from columns 44-45 of the master control record.

Input columns	Variable name	Variable description	Read format
1-3	AGETOT(1)	Total age of stand at 1st report age	F3.0
4-6	AGETOT(2)	Total age of stand at 2d report age	F3.0
7-9	AGETOT(3)	Total age of stand at 3d report age	F3.0
10-12	AGETOT(4)	Total age of stand at 4th report age	F3.0
13-15	AGETOT(5)	Total age of stand at 5th report age	F3.0
16-18	AGETOT(6)	Total age of stand at 6th report age	F3.0
19-21	AGETOT(7)	Total age of stand at 7th report age	F3.0
22-24	AGETOT(8)	Total age of stand at 8th report age	F3.0
25-27	AGETOT(9)	Total age of stand at 9th report age	F3.0
28-30	AGETOT(10)	Total age of stand at 10th report age	F3.0
31-33	AGETOT(11)	Total age of stand at 11th report age	F3.0
34-36	AGETOT(12)	Total age of stand at 12th report age	F3.0
37-39	AGETOT(13)	Total age of stand at 13th report age	F3.0
40-42	AGETOT(14)	Total age of stand at 14th report age	F3.0
43-45	AGETOT(15)	Total age of stand at 15th report age	F3.0
46-48	AGETOT(16)	Total age of stand at 16th report age	F3.0
49-51	AGETOT(17)	Total age of stand at 17th report age	F3.0
52-54	AGETOT(18)	Total age of stand at 18th report age	F3.0
55-57	AGETOT(19)	Total age of stand at 19th report age	F3.0
58-60	AGETOT(20)	Total age of stand at 20th report age	F3.0
61-63	IWW	Length of time growth adjustment effective	I3
64-78		BLANK	
79-80		Input record identification (optional)	

Report height option, input record 3—The number of report heights entered on input record 3 is set by the variable THS from columns 46-47 of the master control record. When this option is used, a report age is set whenever stand height exceeds the smallest previously unused sequential height specified on input record 3.

Input columns	Variable name	Variable description	Read format
1-3	HSPEC(1)	Stand height at 1st report age	F3.0
4-6	HSPEC(2)	Stand height at 2d report age	F3.0
7-9	HSPEC(3)	Stand height at 3d report age	F3.0
10-12	HSPEC(4)	Stand height at 4th report age	F3.0
13-15	HSPEC(5)	Stand height at 5th report age	F3.0
16-18	HSPEC(6)	Stand height at 6th report age	F3.0
19-21	HSPEC(7)	Stand height at 7th report age	F3.0
22-24	HSPEC(8)	Stand height at 8th report age	F3.0
25-27	HSPEC(9)	Stand height at 9th report age	F3.0
28-30	HSPEC(10)	Stand height at 10th report age	F3.0
31-33	HSPEC(11)	Stand height at 11th report age	F3.0
34-36	HSPEC(12)	Stand height at 12th report age	F3.0
37-39	HSPEC(13)	Stand height at 13th report age	F3.0
40-42	HSPEC(14)	Stand height at 14th report age	F3.0
43-45	HSPEC(15)	Stand height at 15th report age	F3.0
46-48	HSPEC(16)	Stand height at 16th report age	F3.0
49-51	HSPEC(17)	Stand height at 17th report age	F3.0
52-54	HSPEC(18)	Stand height at 18th report age	F3.0
55-57	HSPEC(19)	Stand height at 19th report age	F3.0
58-60	HSPEC(20)	Stand height at 20th report age	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

Target basal area option, input record 4—The number of target basal areas entered on input record 4 is set by the variable TGSB from columns 48-49 of the master control record. When this option is used, a report age is set or a commercial thinning is scheduled whenever stand basal area exceeds the next previously unused target basal area set by input record 4.

Input columns	Variable name	Variable description	Read format
1-3	GBMIN(1)	Minimum basal area needed before 1st report age or thinning	F3.0
4-6	GBMIN(2)	Minimum basal area needed before 2d report age or thinning	F3.0
7-9	GBMIN(3)	Minimum basal area needed before 3d report age or thinning	F3.0
10-12	GBMIN(4)	Minimum basal area needed before 4th report age or thinning	F3.0
13-15	GBMIN(5)	Minimum basal area needed before 5th report age or thinning	F3.0
16-18	GBMIN(6)	Minimum basal area needed before 6th report age or thinning	F3.0
19-21	GBMIN(7)	Minimum basal area needed before 7th report age or thinning	F3.0
22-24	GBMIN(8)	Minimum basal area needed before 8th report age or thinning	F3.0
25-27	GBMIN(9)	Minimum basal area needed before 9th report age or thinning	F3.0
28-30	GBMIN(10)	Minimum basal area needed before 10th report age or thinning	F3.0
31-33	GBMIN(11)	Minimum basal area needed before 11th report age or thinning	F3.0
34-36	GBMIN(12)	Minimum basal area needed before 12th report age or thinning	F3.0
37-39	GBMIN(13)	Minimum basal area needed before 13th report age or thinning	F3.0
40-42	GBMIN(14)	Minimum basal area needed before 14th report age or thinning	F3.0
43-45	GBMIN(15)	Minimum basal area needed before 15th report age or thinning	F3.0
46-48	GBMIN(16)	Minimum basal area needed before 16th report age or thinning	F3.0
49-51	GBMIN(17)	Minimum basal area needed before 17th report age or thinning	F3.0
52-54	GBMIN(18)	Minimum basal area needed before 18th report age or thinning	F3.0
55-57	GBMIN(19)	Minimum basal area needed before 19th report age or thinning	F3.0
58-60	GBMIN(20)	Minimum basal area needed before 20th report age or thinning	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

Stand basal area after thinning option, input record 5—The number of basal areas entered on input record 5 is set by the variable TGSA from columns 50-51 of the master control record. This option sets the amount of basal area per acre left after each thinning.

Input columns	Variable name	Variable description	Read format
1-3	GAMIN(1)	Basal area left after 1st thinning	F3.0
4-6	GAMIN(2)	Basal area left after 2d thinning	F3.0
7-9	GAMIN(3)	Basal area left after 3d thinning	F3.0
10-12	GAMIN(4)	Basal area left after 4th thinning	F3.0
13-15	GAMIN(5)	Basal area left after 5th thinning	F3.0
16-18	GAMIN(6)	Basal area left after 6th thinning	F3.0
19-21	GAMIN(7)	Basal area left after 7th thinning	F3.0
22-24	GAMIN(8)	Basal area left after 8th thinning	F3.0
25-27	GAMIN(9)	Basal area left after 9th thinning	F3.0
28-30	GAMIN(10)	Basal area left after 10th thinning	F3.0
31-33	GAMIN(11)	Basal area left after 11th thinning	F3.0
34-36	GAMIN(12)	Basal area left after 12th thinning	F3.0
37-39	GAMIN(13)	Basal area left after 13th thinning	F3.0
40-42	GAMIN(14)	Basal area left after 14th thinning	F3.0
43-45	GAMIN(15)	Basal area left after 15th thinning	F3.0
46-48	GAMIN(16)	Basal area left after 16th thinning	F3.0
49-51	GAMIN(17)	Basal area left after 17th thinning	F3.0
52-54	GAMIN(18)	Basal area left after 18th thinning	F3.0
55-57	GAMIN(19)	Basal area left after 19th thinning	F3.0
58-60	GAMIN(20)	Basal area left after 20th thinning	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

Target stand-density index option, input record 6—The number of target stand-density indices entered on input record 6 is set by the variable NSDIB from columns 52-53 of the master control record. When this option is used, a report age is set or a commercial thinning is scheduled whenever stand-density index of the stand exceeds the next previously unused target stand-density index set by input record 6.

Input columns	Variable name	Variable description	Read format
1-3	SDIB(1)	Minimum stand-density index needed before 1st report age or thinning	F3.0
4-6	SDIB(2)	Minimum stand-density index needed before 2d report age or thinning	F3.0
7-9	SDIB(3)	Minimum stand-density index needed before 3d report age or thinning	F3.0
10-12	SDIB(4)	Minimum stand-density index needed before 4th report age or thinning	F3.0
13-15	SDIB(5)	Minimum stand-density index needed before 5th report age or thinning	F3.0
16-18	SDIB(6)	Minimum stand-density index needed before 6th report age or thinning	F3.0
19-21	SDIB(7)	Minimum stand-density index needed before 7th report age or thinning	F3.0
22-24	SDIB(8)	Minimum stand-density index needed before 8th report age or thinning	F3.0
25-27	SDIB(9)	Minimum stand-density index needed before 9th report age or thinning	F3.0
28-30	SDIB(10)	Minimum stand-density index needed before 10th report age or thinning	F3.0
31-33	SDIB(11)	Minimum stand-density index needed before 11th report age or thinning	F3.0
34-36	SDIB(12)	Minimum stand-density index needed before 12th report age or thinning	F3.0
37-39	SDIB(13)	Minimum stand-density index needed before 13th report age or thinning	F3.0
40-42	SDIB(14)	Minimum stand-density index needed before 14th report age or thinning	F3.0
43-45	SDIB(15)	Minimum stand-density index needed before 15th report age or thinning	F3.0
46-48	SDIB(16)	Minimum stand-density index needed before 16th report age or thinning	F3.0
49-51	SDIB(17)	Minimum stand-density index needed before 17th report age or thinning	F3.0
52-54	SDIB(18)	Minimum stand-density index needed before 18th report age or thinning	F3.0
55-57	SDIB(19)	Minimum stand-density index needed before 19th report age or thinning	F3.0
58-60	SDIB(20)	Minimum stand-density index needed before 20th report age or thinning	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

Stand-density index after thinning option, input record 7—The number of stand-density indices entered on input record 7 is set by the variable NSDIA from columns 54-55 of the master control record. This option sets the stand-density index level the stand has after each thinning.

Input columns	Variable name	Variable description	Read format
1-3	SDIA(1)	SDI after 1st thinning	F3.0
4-6	SDIA(2)	SDI after 2d thinning	F3.0
7-9	SDIA(3)	SDI after 3d thinning	F3.0
10-12	SDIA(4)	SDI after 4th thinning	F3.0
13-15	SDIA(5)	SDI after 5th thinning	F3.0
16-18	SDIA(6)	SDI after 6th thinning	F3.0
19-21	SDIA(7)	SDI after 7th thinning	F3.0
22-24	SDIA(8)	SDI after 8th thinning	F3.0
25-27	SDIA(9)	SDI after 9th thinning	F3.0
28-30	SDIA(10)	SDI after 10th thinning	F3.0
31-33	SDIA(11)	SDI after 11th thinning	F3.0
34-36	SDIA(12)	SDI after 12th thinning	F3.0
37-39	SDIA(13)	SDI after 13th thinning	F3.0
40-42	SDIA(14)	SDI after 14th thinning	F3.0
43-45	SDIA(15)	SDI after 15th thinning	F3.0
46-48	SDIA(16)	SDI after 16th thinning	F3.0
49-51	SDIA(17)	SDI after 17th thinning	F3.0
52-54	SDIA(18)	SDI after 18th thinning	F3.0
55-57	SDIA(19)	SDI after 19th thinning	F3.0
58-60	SDIA(20)	SDI after 20th thinning	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

Trees per acre after thinning option, input record 8—The number of data fields read from input record 8 is controlled by the variable NTASP, which is in columns 56-57 of the master control record. This option sets the trees per acre a stand will have after each thinning.

Input columns	Variable name	Variable description	Read format
1-3	SPTA(1)	Trees per acre left after 1st thinning	F3.0
4-6	SPTA(2)	Trees per acre left after 2d thinning	F3.0
7-9	SPTA(3)	Trees per acre left after 3d thinning	F3.0
10-12	SPTA(4)	Trees per acre left after 4th thinning	F3.0
13-15	SPTA(5)	Trees per acre left after 5th thinning	F3.0
16-18	SPTA(6)	Trees per acre left after 6th thinning	F3.0
19-21	SPTA(7)	Trees per acre left after 7th thinning	F3.0
22-24	SPTA(8)	Trees per acre left after 8th thinning	F3.0
25-27	SPTA(9)	Trees per acre left after 9th thinning	F3.0
28-30	SPTA(10)	Trees per acre left after 10th thinning	F3.0
31-33	SPTA(11)	Trees per acre left after 11th thinning	F3.0
34-36	SPTA(12)	Trees per acre left after 12th thinning	F3.0
37-39	SPTA(13)	Trees per acre left after 13th thinning	F3.0
40-42	SPTA(14)	Trees per acre left after 14th thinning	F3.0
43-45	SPTA(15)	Trees per acre left after 15th thinning	F3.0
46-48	SPTA(16)	Trees per acre left after 16th thinning	F3.0
49-51	SPTA(17)	Trees per acre left after 17th thinning	F3.0
52-54	SPTA(18)	Trees per acre left after 18th thinning	F3.0
55-57	SPTA(19)	Trees per acre left after 19th thinning	F3.0
58-60	SPTA(20)	Trees per acre left after 20th thinning	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

DCUT / DMERCH ratio option, input record 9—The number of data fields read from input record 9 is controlled by the variable DRAT, which is specified in columns 68-69 of the master control record. This option allows the user to control the size of tree cut during a thinning. The present version of PPSIM requires the DCUT/DMERCH ratio to be between 0.9 and 1.1.

Input columns	Variable name	Variable description	Read format
1-3	DR(1)	DCUT/DMERCH ratio for 1st thinning	F3.2
4-6	DR(2)	DCUT/DMERCH ratio for 2d thinning	F3.2
7-9	DR(3)	DCUT/DMERCH ratio for 3d thinning	F3.2
10-12	DR(4)	DCUT/DMERCH ratio for 4th thinning	F3.2
13-15	DR(5)	DCUT/DMERCH ratio for 5th thinning	F3.2
16-18	DR(6)	DCUT/DMERCH ratio for 6th thinning	F3.2
19-21	DR(7)	DCUT/DMERCH ratio for 7th thinning	F3.2
22-24	DR(8)	DCUT/DMERCH ratio for 8th thinning	F3.2
25-27	DR(9)	DCUT/DMERCH ratio for 9th thinning	F3.2
28-30	DR(10)	DCUT/DMERCH ratio for 10th thinning	F3.2
31-33	DR(11)	DCUT/DMERCH ratio for 11th thinning	F3.2
34-36	DR(12)	DCUT/DMERCH ratio for 12th thinning	F3.2
37-39	DR(13)	DCUT/DMERCH ratio for 13th thinning	F3.2
40-42	DR(14)	DCUT/DMERCH ratio for 14th thinning	F3.2
43-45	DR(15)	DCUT/DMERCH ratio for 15th thinning	F3.2
46-48	DR(16)	DCUT/DMERCH ratio for 16th thinning	F3.2
49-51	DR(17)	DCUT/DMERCH ratio for 17th thinning	F3.2
52-54	DR(18)	DCUT/DMERCH ratio for 18th thinning	F3.2
55-57	DR(19)	DCUT/DMERCH ratio for 19th thinning	F3.2
58-60	DR(20)	DCUT/DMERCH ratio for 20th thinning	F3.2
61-78		BLANK	
79-80		Input record identification (optional)	

Fertilizer and growth adjustment age option, input record 10—The number of data fields read from input record 10 is controlled by the variable FAS, which is specified in columns 61-62 of the master control record. This option allows the user to fertilize or adjust growth at any age during the life of a stand.

Input columns	Variable name	Variable description	Read format
1-3	AFERT(1)	Stand age at 1st growth adjustment	F3.0
4-6	AFERT(2)	Stand age at 2d growth adjustment	F3.0
7-9	AFERT(3)	Stand age at 3d growth adjustment	F3.0
10-12	AFERT(4)	Stand age at 4th growth adjustment	F3.0
13-15	AFERT(5)	Stand age at 5th growth adjustment	F3.0
16-18	AFERT(6)	Stand age at 6th growth adjustment	F3.0
19-21	AFERT(7)	Stand age at 7th growth adjustment	F3.0
22-24	AFERT(8)	Stand age at 8th growth adjustment	F3.0
25-27	AFERT(9)	Stand age at 9th growth adjustment	F3.0
28-30	AFERT(10)	Stand age at 10th growth adjustment	F3.0
31-33	AFERT(11)	Stand age at 11th growth adjustment	F3.0
34-36	AFERT(12)	Stand age at 12th growth adjustment	F3.0
37-39	AFERT(13)	Stand age at 13th growth adjustment	F3.0
40-42	AFERT(14)	Stand age at 14th growth adjustment	F3.0
43-45	AFERT(15)	Stand age at 15th growth adjustment	F3.0
46-48	AFERT(16)	Stand age at 16th growth adjustment	F3.0
49-51	AFERT(17)	Stand age at 17th growth adjustment	F3.0
52-54	AFERT(18)	Stand age at 18th growth adjustment	F3.0
55-57	AFERT(19)	Stand age at 19th growth adjustment	F3.0
58-60	AFERT(20)	Stand age at 20th growth adjustment	F3.0
61-63	IWW	Length of time growth adjustment effective	I3
64-78		BLANK	
79-80		Input record identification (optional)	

Percentage of growth adjustment option, input record 11—The number of data fields read from input record 11 is controlled by the variable FPC, which is specified in columns 63-64 of the master control record. In input record 11, the user specifies the percentage of growth adjustment, either positive or negative, to simulate changes in the rate of growth that may occur at or between report ages. The effects of fertilization, impacts of insects and disease, and variations in growth caused by climatic changes can be simulated using this option.

Input columns	Variable name	Variable description	Read format
1-3	PFERT(1)	Percent growth adjustment at 1st adjustment age	F3.0
4-6	PFERT(2)	Percent growth adjustment at 2d adjustment age	F3.0
7-9	PFERT(3)	Percent growth adjustment at 3d adjustment age	F3.0
10-12	PFERT(4)	Percent growth adjustment at 4th adjustment age	F3.0
13-15	PFERT(5)	Percent growth adjustment at 5th adjustment age	F3.0
16-18	PFERT(6)	Percent growth adjustment at 6th adjustment age	F3.0
19-21	PFERT(7)	Percent growth adjustment at 7th adjustment age	F3.0
22-24	PFERT(8)	Percent growth adjustment at 8th adjustment age	F3.0
25-27	PFERT(9)	Percent growth adjustment at 9th adjustment age	F3.0
28-30	PFERT(10)	Percent growth adjustment at 10th adjustment age	F3.0
31-33	PFERT(11)	Percent growth adjustment at 11th adjustment age	F3.0
34-36	PFERT(12)	Percent growth adjustment at 12th adjustment age	F3.0
37-39	PFERT(13)	Percent growth adjustment at 13th adjustment age	F3.0
40-42	PFERT(14)	Percent growth adjustment at 14th adjustment age	F3.0
43-45	PFERT(15)	Percent growth adjustment at 15th adjustment age	F3.0
46-48	PFERT(16)	Percent growth adjustment at 16th adjustment age	F3.0
49-51	PFERT(17)	Percent growth adjustment at 17th adjustment age	F3.0
52-54	PFERT(18)	Percent growth adjustment at 18th adjustment age	F3.0
55-57	PFERT(19)	Percent growth adjustment at 19th adjustment age	F3.0
58-60	PFERT(20)	Percent growth adjustment at 20th adjustment age	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

Number of infected trees per acre left after thinning option, input record12– The number of data fields read from input record 12 is controlled by the variable NINFSP, which is specified in columns 75-76 of the master control record. Input record 12 allows the user to override the program assumption that the ratio of infected trees to healthy trees will not change during thinning.

Input columns	Variable name	Variable description	Read format
1-3	TAINF(1)	Number of infected trees per acre left after 1st thinning	F3.0
4-6	TAINF(2)	Number of infected trees per acre left after 2d thinning	F3.0
7-9	TAINF(3)	Number of infected trees per acre left after 3d thinning	F3.0
10-12	TAINF(4)	Number of infected trees per acre left after 4th thinning	F3.0
13-15	TAINF(5)	Number of infected trees per acre left after 5th thinning	F3.0
16-18	TAINF(6)	Number of infected trees per acre left after 6th thinning	F3.0
19-21	TAINF(7)	Number of infected trees per acre left after 7th thinning	F3.0
22-24	TAINF(8)	Number of infected trees per acre left after 8th thinning	F3.0
25-27	TAINF(9)	Number of infected trees per acre left after 9th thinning	F3.0
28-30	TAINF(10)	Number of infected trees per acre left after 10th thinning	F3.0
31-33	TAINF(11)	Number of infected trees per acre left after 11th thinning	F3.0
34-36	TAINF(12)	Number of infected trees per acre left after 12th thinning	F3.0
37-39	TAINF(13)	Number of infected trees per acre left after 13th thinning	F3.0
40-42	TAINF(14)	Number of infected trees per acre left after 14th thinning	F3.0
43-45	TAINF(15)	Number of infected trees per acre left after 15th thinning	F3.0
46-48	TAINF(16)	Number of infected trees per acre left after 16th thinning	F3.0
49-51	TAINF(17)	Number of infected trees per acre left after 17th thinning	F3.0
52-54	TAINF(18)	Number of infected trees per acre left after 18th thinning	F3.0
55-57	TAINF(19)	Number of infected trees per acre left after 19th thinning	F3.0
58-60	TAINF(20)	Number of infected trees per acre left after 20th thinning	F3.0
61-78		BLANK	
79-80		Input record identification (optional)	

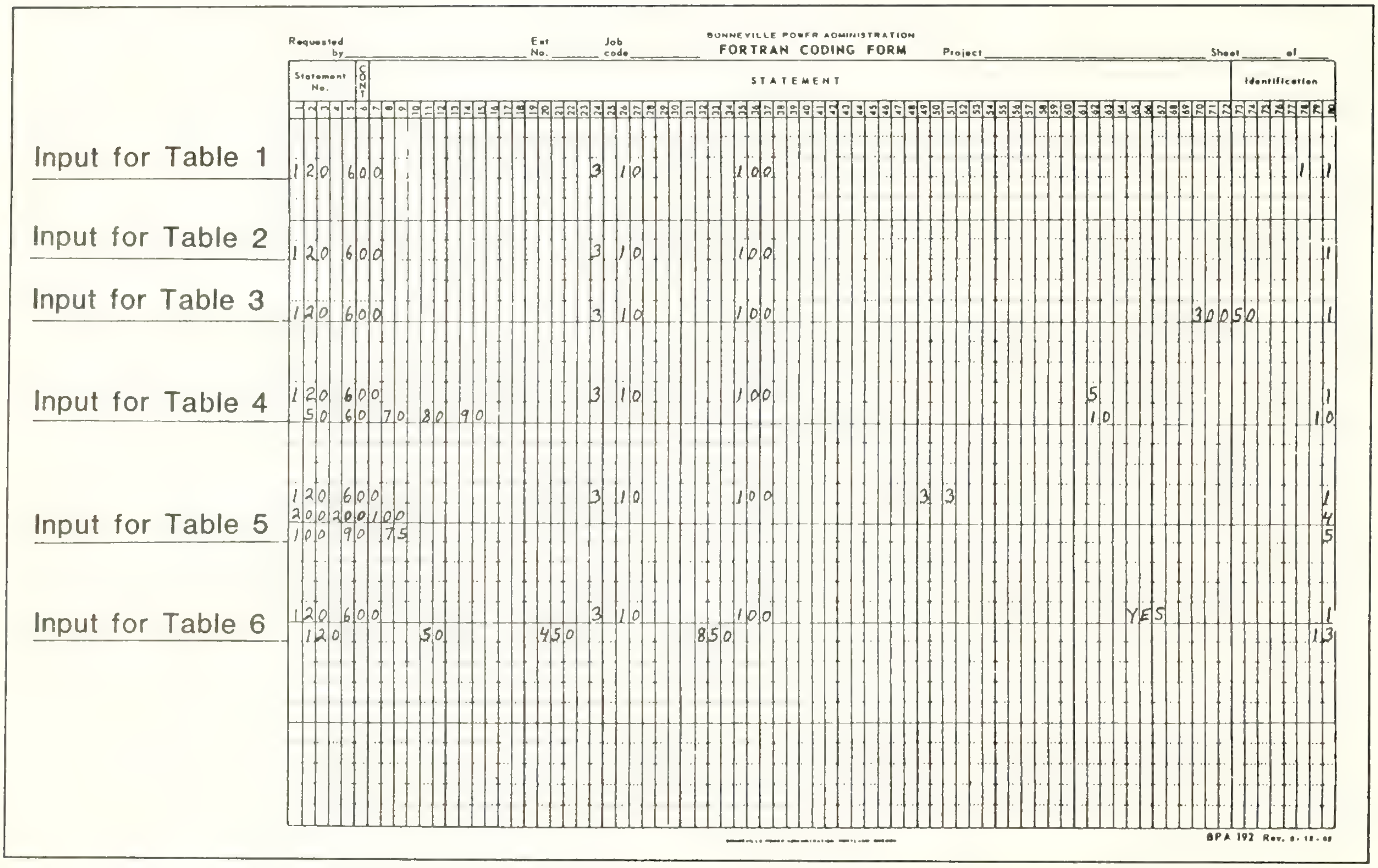
Starting stand-statistic option, input record 13—Forest managers often want to predict the growth of an existing forest stand under various management treatments. An option is available in PPSIM that allows for the entry of starting-stand statistics of an existing stand and the projection of growth of the entered stand when a set of management treatments is given. Normally, all stand variables needed to describe an existing stand are specified on the starting stand-statistics input record; however, site index can be set on either input record 13 or the master control input record. The reading of input record 13 is controlled by the variable SSS (columns 65-67) of the master control input record.

Input columns	Variable name	Variable description	Read format
1-4	STSITE	Site index of the stand based on Barrett's site curves: If STSITE is blank or zero, then STSITE is set equal to SIB of the master control record; if both variables are blank or zero, then STSITE is calculated from an equation that has STTAGE and STHT as input variables	F4.0
5-8	STHT	Height of the five tallest trees in the stand: If STHT is blank or zero, then STHT is calculated from an equation that has STSITE and STTAGE as input variables	F4.0
9-12	STTAGE	Total age of stand at the start of the growth simulation: If STTAGE is blank or zero, then STTAGE is calculated from an equation that uses STSITE and age at breast height (STAGE) as input variables	F4.0
13-16	STAGE	Breast-height age of the stand at the start of the growth simulation: If STAGE is blank or zero, then STAGE is calculated from an equation that uses STTAGE and STSITE as input variables	F4.0
17-22	STTA	Number of trees per acre at the start of the growth simulation: If STTA is blank or zero, then a value for STTA will be derived from the quadratic mean diameter (STDBH) and basal area per acre (STGA)	F6.0
23-28	STGA	Basal area per acre of the stand at the start of the growth simulation: If STGA is blank or zero, then a value for STGA is derived from STDBH and STTA	F6.2
29-34	STDBH	Quadratic mean diameter of the stand at the start of the growth simulation: If STDBH is blank or zero, then a value for STDBH is derived from STGA and STTA	F6.2
35-78		BLANK	
79-80		Input record identification (optional)	

NOTE: STTA, STGA, and STDBH should be mathematically consistent when all the variables are specified. Also, at least two of these variables must be set before a growth simulation can proceed.

Appendix 3: Program Examples

Program Input Example



Requested by____ Ext No.____ Job code____

BONNEVILLE POWER ADMINISTRATION
FORTRAN CODING FORM

Project____ Sheet____ of____

Statement No. | CONT | STATEMENT | Identification

Input for Table 1

```
120 600                3 10       100                                        1 1
```

Input for Table 2

```
120 600                3 10       100                                          1
```

Input for Table 3

```
120 600                3 10       100                                30050     1
```

Input for Table 4

```
120 600                3 10       100                        5                 1
 50 60 70 80 90                                              10               10
```

Input for Table 5

```
120 600                3 10       100           3 3                            1
200200100                                                                      4
100 90 75                                                                      5
```

Input for Table 6

```
120 600                3 10       100                           YES            1
 120      50       450         850                                            13
```

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Figure 2—Program input needed to produce example output tables.

Output Tables

Output table 1—Natural-stand table for site index 120. Report ages selected to coincide with managed-stand tables.

```
                          PONDEROSA PINE
                     (PINUS PONDEROSA LAWS.)

                       NATURAL STAND TABLE



                     BARRETT SITE INDEX=120.

 VARIABLES ON MASTER CONTROL RECORD SPECIFY THAT

   MINIMUM DIAMETER OF A MERCHANTABLE TREE=  6.00
   NUMBER OF THINNING OR OUTPUT AGES=  3
   NUMBER OF YEARS BETWEEN THINNING OR OUTPUT AGES=10.
   HARVEST AGE=100.




                                  MEAN    MEAN    MEAN              G     CU FT
TOTAL  STAND                      TREE    TREE    TREE    TREES    PER    VOLUME
 AGE   HEIGHT    STAND            DBH      G      VOL.     PER     ACRE    PER
YEARS   FEET   COMPONENT         INCHES  SQ FT   CU FT    ACRE    SQ FT   ACRE

 50.   66.3    FIRST AGE          7.1    .276      5.5    718.2   198.4  3946.
               SUBMERCH           3.8    .079      1.0    398.6    31.7   391.
               MERCH PART         9.8    .522     11.1    319.6   166.8  3555.
               NO THINNING

               PERIOD MORT        4.9    .129      1.9    211.8    27.4   401.

 60.   78.7    TOTAL STAND        8.7    .412      9.6    506.4   208.4  4840.
               SUBMERCH           4.0    .087      1.2    204.3    17.8   244.
               MERCH PART        10.8    .631     15.2    302.0   190.6  4596.
               NO THINNING

               PERIOD MORT        4.9    .131      2.1    124.8    16.4   260.

 70.   89.5    TOTAL STAND       10.1    .560     14.6    381.6   213.8  5577.
               SUBMERCH           4.2    .095      1.4    108.8    10.3   156.
               MERCH PART        11.7    .746     19.9    272.8   203.5  5421.
               NO THINNING

               PERIOD MORT        6.9    .256      5.4    182.6    46.7   994.

100.  113.7    HARVEST CUT       14.1   1.082     35.0    199.0   215.2  6973.
               SUBMERCH           4.8    .128      2.5     13.5     1.7    34.
               MERCH PART        14.5   1.151     37.4    185.4   213.5  6940.
```

Output table 2—Managed-stand table for site index 120. Up to the time of thinning, stand was in a natural state.

```
                              PONDEROSA PINE
                          (PINUS PONDEROSA LAWS.)

                            MANAGED STAND TABLE

                          BARRETT SITE INDEX=120.

 VARIABLES ON MASTER CONTROL RECORD SPECIFY THAT

   MINIMUM DIAMETER OF A MERCHANTABLE TREE=  6.00
   NUMBER OF THINNING OR OUTPUT AGES=  3
   NUMBER OF YEARS BETWEEN THINNING OR OUTPUT AGES=10.
   HARVEST AGE=100.




                              MEAN    MEAN    MEAN              G      CU FT
TOTAL  STAND                  TREE    TREE    TREE    TREES    PER    VOLUME
 AGE   HEIGHT    STAND        DBH      G      VOL.     PER    ACRE     PER
YEARS   FEET   COMPONENT     INCHES  SQ FT   CU FT    ACRE    SQ FT    ACRE

 50.    66.3   FIRST AGE       7.1   .276      5.5    718.2   198.4   3946.
               SUBMERCH        3.8   .079      1.0    398.6    31.7    391.
               MERCH PART      9.8   .522     11.1    319.6   166.8   3555.
               CUT             9.8   .522     11.1    192.0   100.2   2135.
               TOTAL LEAVE     9.8   .522     11.1    127.6    66.6   1419.

 60.    78.7   TOTAL STAND    11.5   .723     17.8    127.6    92.3   2275.
               CUT            11.5   .723     17.8     31.1    22.5    554.
               TOTAL LEAVE    11.5   .723     17.8     96.6    69.8   1721.

 70.    89.5   TOTAL STAND    13.3   .964     26.5     96.6    93.1   2563.
               CUT            13.3   .964     26.5     21.1    20.4    560.
               TOTAL LEAVE    13.3   .964     26.5     75.5    72.8   2003.

100.   113.7   HARVEST CUT    17.5  1.665     56.3     75.5   125.7   4252.
```

Output table 3—Managed stand with dwarf mistletoe—site index 120. Note that at age 50, program output is the same as managed-stand output without dwarf mistletoe. This is not reasonable and points out that the dwarf mistletoe option should be used only when an actual stand is input via the starting stand-statistics record (input record 13).

```
                                        PONDEROSA PINE
                                    (PINUS PONDEROSA LAWS.)

                                      MANAGED STAND TABLE

                                    BARRETT SITE INDEX=120.

 VARIABLES ON MASTER CONTROL RECORD SPECIFY THAT

   MINIMUM DIAMETER OF A MERCHANTABLE TREE=  6.00
   NUMBER OF THINNING OR OUTPUT AGES=  3
   NUMBER OF YEARS BETWEEN THINNING OR OUTPUT AGES=10.
   HARVEST AGE=100.
   TOTAL AGE OF STAND WHEN MISTLETOE INFESTATION WAS OBSERVED= 50 NUMBER
   OF TREES WITH DWARF MISTLETOE AT AGE OF OBSERVATION=300




                                    MEAN    MEAN    MEAN                G      CU FT
TOTAL  STAND                        TREE    TREE    TREE    TREES      PER     VOLUME
 AGE   HEIGHT     STAND             DBH      G      VOL.     PER       ACRE     PER
YEARS   FEET    COMPONENT          INCHES  SQ FT   CU FT    ACRE       SQ FT    ACRE

 50.    66.3   FIRST AGE            7.1    .276      5.5    718.2     198.4   3946.
               SUBMERCH             3.8    .079      1.0    398.6      31.7    391.
               MERCH PART           9.8    .522     11.1    319.6     166.8   3555.
               CUT                  9.8    .522     11.1    192.0     100.2   2135.
               TOTAL LEAVE          9.8    .522     11.1    127.6      66.6   1419.

 60.    78.7   TOTAL STAND         11.0    .659     16.3    127.6      84.1   2074.
               CUT                 11.0    .659     16.3     23.1      15.2    376.
               TOTAL LEAVE         11.0    .659     16.3    104.5      68.9   1699.

 70.    89.5   TOTAL STAND         12.4    .832     22.9    104.5      87.0   2393.
               CUT                 12.4    .832     22.9     18.9      15.7    433.
               TOTAL LEAVE         12.4    .832     22.9     85.6      71.3   1961.

100.   113.7   HARVEST CUT         16.1   1.407     47.6     85.6     120.4   4074.
```

Output table 4—Managed stand that was fertilized at ages specified on input record 10. Site index 120.

```
                          PONDEROSA PINE
                      (PINUS PONDEROSA LAWS.)

                        MANAGED STAND TABLE

                      BARRETT SITE INDEX 120.

VARIABLES ON MASTER CONTROL RECORD SPECIFY THAT

   MINIMUM DIAMETER OF A MERCHANTABLE TREE=  6.00
   NUMBER OF THINNING OR OUTPUT AGES=  3
   NUMBER OF YEARS BETWEEN THINNING OR OUTPUT AGES=10.
   HARVEST AGE=100.
   STAND VOLUME GROWTH IS ADJUSTED AT THE AGES SPECIFIED ON CARD TYPE 10. GROWTH
   ADJUSTMENT AGES ARE: 50. 60. 70. 80. 90.
   THE GROWTH ADJUSTMENTS ARE CALCULATED BY THE FERTILIZER EQUATION. A GROWTH
   ADJUSTMENT WILL INFLUENCE THE GROWTH OF A STAND FOR A PERIOD OF 10 YEARS
   AFTER THE ADJUSTMENT AGE.
   ONLY TWO GROWTH ADJUSTMENTS CAN AFFECT THE STAND AT ANY ONE TIME.




                           MEAN    MEAN    MEAN              G      CU FT
TOTAL  STAND               TREE    TREE    TREE    TREES    PER     VOLUME
 AGE   HEIGHT    STAND     DBH      G      VOL.     PER     ACRE     PER
YEARS   FEET   COMPONENT  INCHES  SQ FT   CU FT    ACRE    SQ FT    ACRE

 50.   66.3   FIRST AGE     7.1   .276      5.5   718.2   198.4   3946.
              SUBMERCH      3.8   .079      1.0   398.6    31.7    391.
              MERCH PART    9.8   .522     11.1   319.6   166.8   3555.
              CUT           9.8   .522     11.1   192.0   100.2   2135.
              TOTAL LEAVE   9.8   .522     11.1   127.6    66.6   1419.

 60.   80.3   TOTAL STAND  11.7   .744     18.7   127.6    95.0   2382.
              CUT          11.7   .744     18.7    33.5    24.9    625.
              TOTAL LEAVE  11.7   .744     18.7    94.2    70.1   1758.

 70.   92.5   TOTAL STAND  13.7  1.019     28.8    94.2    95.9   2714.
              CUT          13.7  1.019     28.8    22.1    22.6    638.
              TOTAL LEAVE  13.7  1.019     28.8    72.0    73.4   2076.

100.  118.1   HARVEST CUT  19.2  2.013     70.4    72.0   145.0   5069.
```

Output table 5—Managed-stand output where thinning ages are specified but scheduled thinnings are allowed only if stand attains a predetermined basal area. Basal area of the stand after thinning is also set using input record 5. Site index 120.

```
                         PONDEROSA PINE
                     (PINUS PONDEROSA LAWS.)

                       MANAGED STAND TABLE

                     BARRETT SITE INDEX=120.

 VARIABLES ON MASTER CONTROL RECORD SPECIFY THAT

   MINIMUM DIAMETER OF A MERCHANTABLE TREE=  6.00
   NUMBER OF THINNING OR OUTPUT AGES=  3
   NUMBER OF YEARS BETWEEN THINNING OR OUTPUT AGES=10.
   HARVEST AGE=100.



   VARIABLES FROM OPTIONAL INPUT RECORDS ARE:


                                                                RATIO
                                                              DIAMETER NUMBER OF
                           SQ.FT. SQ.FT. STAND   STAND  TREES  CUT TO    DWARF
 REPORT   REPORT           BASAL  BASAL DENSITY DENSITY  PER  DIAMETER MISTLETOE
   OR       OR              AREA   AREA  INDEX   INDEX  ACRE   MERCH.    TREES
THINNING THINNING THINNING BEFORE AFTER  BEFORE  AFTER  AFTER PART OF    AFTER
 NUMBER     AGE     HEIGHT  CUT    CUT    CUT     CUT    CUT   STAND      CUT
   1        0.         0.  200.   100.     0.      0.     0.     .0        0.
   2        0.         0.  200.    90.     0.      0.     0.     .0        0.
   3        0.         0.  100.    75.     0.      0.     0.     .0        0.



                            MEAN   MEAN   MEAN               G      CU FT
TOTAL  STAND                TREE   TREE   TREE   TREES      PER     VOLUME
 AGE   HEIGHT    STAND      DBH     G     VOL.    PER      ACRE      PER
YEARS   FEET   COMPONENT   INCHES  SQ FT  CU FT  ACRE      SQ FT    ACRE

 50.   66.3   FIRST AGE      7.1   .276     5.5   718.2   198.4  3946.

 52.   69.0   TOTAL STAND    7.4   .302     6.2   664.9   200.9  4137.
              SUBMERCH       3.9   .081     1.0   346.9    28.1   352.
              MERCH PART    10.0   .543    11.9   318.0   172.7  3785.
              CUT           10.0   .543    11.9   133.9    72.7  1594.
              TOTAL LEAVE   10.0   .543    11.9   184.1   100.0  2191.

 62.   81.0   TOTAL STAND   10.8   .636    16.0   184.1   117.0  2943.
              G UNDER MIN
              NO THINNING
              TOTAL LEAVE   10.8   .636    16.0   184.1   117.0  2943.

 72.   91.5   TOTAL STAND   11.2   .690    19.3   184.1   127.0  3546.
              CUT           11.2   .690    19.3    75.4    52.0  1453.
              TOTAL LEAVE   11.2   .690    19.3   108.7    75.0  2094.

100.  113.7   HARVEST CUT   14.5  1.148    38.7   108.7   124.8  4208.
```

Output table 6—Managed-stand output—site index 120. Starting stand specified using starting stand-statistics record.

```
                          PONDEROSA PINE
                      (PINUS PONDEROSA LAWS.)

                        MANAGED STAND TABLE

                      BARRETT SITE INDEX=120.

 VARIABLES ON MASTER CONTROL RECORD SPECIFY THAT

   MINIMUM DIAMETER OF A MERCHANTABLE TREE=   6.00
   NUMBER OF THINNING OR OUTPUT AGES=  3
   NUMBER OF YEARS BETWEEN THINNING OR OUTPUT AGES=10.
   HARVEST AGE=100.




                      BARRETT SITE INDEX=120.


 THE STARTING STAND IS SPECIFIED


                                    MEAN    MEAN    MEAN              G      CU FT
TOTAL  STAND                        TREE    TREE    TREE    TREES    PER    VOLUME
 AGE   HEIGHT      STAND            DBH      G      VOL.     PER     ACRE     PER
YEARS   FEET     COMPONENT         INCHES  SQ FT   CU FT    ACRE     SQ FT   ACRE

 50.     66.    START STAND          8.5    .394     7.8    450.0    177.3   3526.
                CUT                  8.5    .394     7.8    287.7    113.4   2254.
                TOTAL LEAVE          8.5    .394     7.8    162.3     63.9   1271.

 60.    78.7    TOTAL STAND         10.1    .561    13.0    162.3     91.1   2115.
                CUT                 10.1    .561    13.0     42.4     23.8    552.
                TOTAL LEAVE         10.1    .561    13.0    119.9     67.3   1563.

 70.    89.5    TOTAL STAND         11.8    .765    20.0    119.9     91.7   2393.
                CUT                 11.8    .765    20.0     27.9     21.3    557.
                TOTAL LEAVE         11.8    .765    20.0     92.0     70.4   1836.

100.   113.7    HARVEST CUT         15.8   1.368    44.3     92.0    125.9   4078.
```

DeMars, Donald J.; Barrett, James W. 1987. Ponderosa pine managed yield simulator: PPSIM users guide Gen Tech Rep PNW-GTR-203 Portland, OR U S Department of Agriculture, Forest Service, Pacific Northwest Research Station. 36 p

PPSIM simulates yields of natural and managed ponderosa pine stands Management practices and effects that can be simulated include commercial thinning, fertilization, genetic improvement, and presence of dwarf mistletoe An option is available that adjusts growth to simulate local conditions Equations used in PPSIM describe growth of natural stands, estimate the volume increment of thinned stands, and predict the amount and timing of mortality in natural stands The Fortran IV program is available from the authors on request

Keywords: Simulation, computer programs/programing, yield (forest), ponderosa pine, *Pinus ponderosa*

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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General Technical
Report
PNW-GTR-204

REACTT: An Algorithm for Solving Spatial Equilibrium Problems

David J. Brooks and Jonna Kincaid

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Abstract

Brooks, David J.; Kincaid, Jonna. 1987. REACTT: an algorithm for solving spatial equilibrium problems. Gen. Tech. Rep. PNW-GTR-204. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37 p.

The problem of determining equilibrium prices and quantities in spatially separated markets is reviewed. Algorithms that compute spatial equilibria are discussed. A computer program using the reactive programming algorithm for solving spatial equilibrium problems that involve multiple commodities is presented, along with detailed documentation. A sample data set, program output, and a partial program listing are also provided.

Keywords: Computer programs/programing, models, supply/demand (forest products).

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Introduction

Computer models of supply and demand for commodities in spatially separated markets have been widely used to examine the behavior of producers and consumers and to investigate market equilibrium conditions under alternative policies. But in spite of their fundamental importance, methods of model solution are seldom discussed in any detail when analytical results are presented. This practice can be partially attributed to descriptive parsimony by researchers and partially to disinterest in much of the audience.

The solution method, nevertheless, determines many of the essential characteristics of any model of market behavior and should be given attention. Among the characteristics determined by the solution method are the permissible form (or forms) of the functional relationships of a model and the model's endogenous and exogenous variables. Some solution methods impose restrictions on the behavioral relationships of a model. The solution method also has an effect on the ease with which repeated solutions can be reached, either for sensitivity analysis or for policy analysis. A solution method that is either computationally difficult or expensive can provide a correct answer but may severely limit the usefulness of a model.

This report provides a general introduction to the spatial equilibrium problem and documents a multiregion, multicommodity, spatial equilibrium solution algorithm that is a revision of the "reactive programming" approach first developed by Tramel and Seale (1959). This algorithm has undergone many revisions since it was first presented, revisions that have improved its performance and expanded its capabilities. Reactive programming is an inexpensive, simple, and flexible solution algorithm. Yet, in spite of these desirable characteristics, it has not been widely used. The version of reactive programming reported here incorporates the contributions of many individuals and illustrates some of the extensions to the technique envisaged by Tramel and Seale (1959) over two decades ago.

Spatial Price Equilibrium

The conditions for spatial price equilibrium for multiple products can be stated formally as follows:

Let P_{jk} indicate the price of product k in market j (k=1,K; j=1,M); X_{jk} is the quantity of product k consumed in market j; C_{ik} is the supply price (production cost) for product k in supply region i (i=1,N); PT_{ik} is the quantity of product k produced in supply region i; q_{ijk} is the quantity of product k shipped from region i to market j; TC_{ijk} is the unit cost for shipping product k from i to j; and t_{ijk} is the ad valorem tariff imposed by market j on shipments of product k from supply region i.

Demand functions (equation 1) express the price of each product as a function of the consumption of that product and all other products; supply functions (equation 2) express the cost of each product as a function of the production of that product and all other products:

$$P_{jk} = p(X_{j1},...,X_{jk}) \text{ ;and} \tag{1}$$

$$C_{ik} = c(PT_{i1},...,PT_{jk}) . \tag{2}$$

Consumption in any market must be less than or equal to the sum of shipments from all producing regions; production in any region must be greater than or equal to the sum of shipments to all markets. Taken together, equations (3) and (4) hold as strict equalities and impose an accounting balance on shipments:

$$X_{jk} \leq \sum_{i} q_{ijk} \text{ ; and} \tag{3}$$

$$PT_{ik} \geq \sum_{j} q_{ijk} . \tag{4}$$

An important characteristic of competitive markets in equilibrium is that excess profit for all suppliers will be zero. Excess profit (or quasi-rent) is a phenomenon of shortrun disequilibrium and can be defined as a return to a producer that is greater than the production (opportunity) cost. The return to a producer is the price in any market minus transportation cost, tariff charges, and production cost. The supply function (equation 2) is defined such that the cost (C_{ik}) includes all relevant costs, including normal profit. Equations (5) and (6) express the competitive market equilibrium condition:

$$P_{jk} - TC_{ijk} - C_{ik} - t_{ijk}C_{ik} \leq 0 \text{ ; and} \tag{5}$$

$$\sum_{i}\sum_{j}\sum_{k} (P_{jk} - TC_{ijk} - C_{ik} - t_{ijk}C_{ik})q_{ijk} = 0 . \tag{6}$$

Finally, all quantities and prices must be nonnegative:

$$q_{ijk}, P_{jk}, C_{ik}, X_{jk}, PT_{ik} \geq 0 . \tag{7}$$

The adjustment process that leads competitive markets to an equilibrium position with zero excess profit is illustrated in figure 1. Each producer is a price-taker, and market demand, D^M, is perfectly elastic at market price P^M. For expositional simplicity, transportation costs and tariffs are assumed to be zero. Market supply is indicated by S^M. At quantity q_1, positive excess profits exist, and producers will increase supply (with increasing marginal cost) until an additional unit of output costs more to produce than consumers are willing to pay. At quantity q_2, production costs exceed the market price, and producers will reduce output until excess profit is nonnegative. Quantity adjustment is the only option available to producers in a competitive market.

Samuelson (1952) describes (for a single product) how the spatial equilibrium problem can be set up as a maximization problem and be solved using linear programming. He

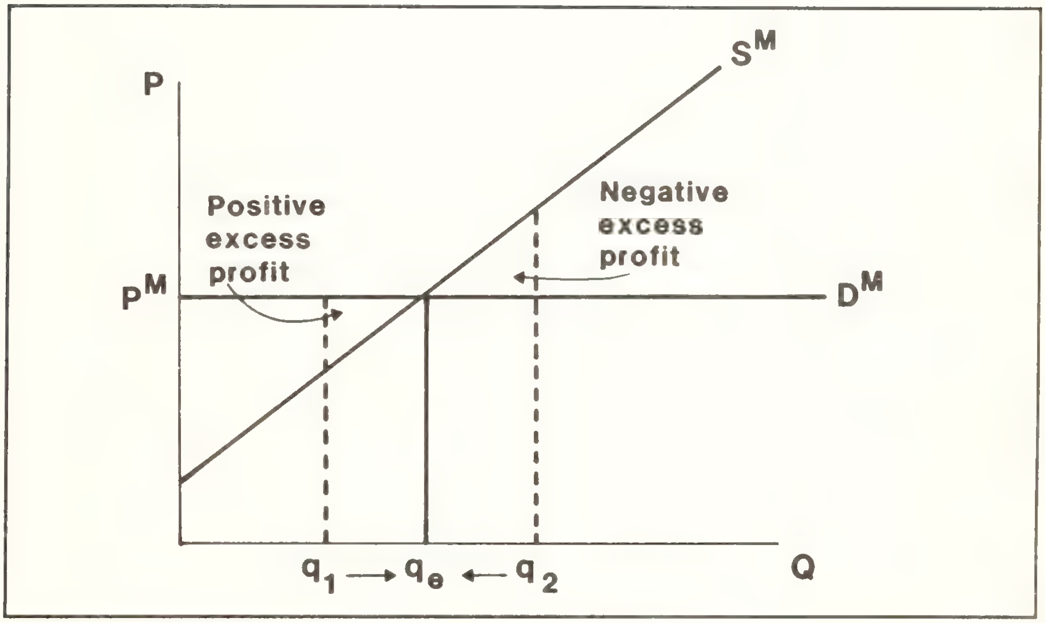

Figure 1—Quantity adjustment by suppliers in a competitive market.

defines the quantity to be maximized as the "net social payoff" (NSP), which is equivalent to the sum of producer and consumer surpluses minus transportation costs. Producer surplus is the area bounded by the supply curve and market price; consumer surplus is the area bounded by the demand curve and market price. Samuelson (1952) shows the correspondence between the maximum of the NSP function and multiregion equilibrium conditions. The NSP function is artificial in the sense that no participants in the market have any reason to be aware of it; Samuelson (1952) notes the similarity between this maximization and Adam Smith's "invisible hand."

Samuelson (1952) also points out that maximizing the NSP function will result in a pattern of shipments that minimizes transportation costs. Smith (1963) demonstrates the formal equivalence between the dual of this maximization problem and the conditions of competitive equilibrium. That is, in competitive markets excess profit (quasi-rent) is minimized because it is eliminated.

Takayama and Judge (1964) extend Samuelson's (1952) results to the multiproduct case and solve the resulting problem using quadratic programming techniques. McCarl and others (1984) provide documentation on an algorithm that solves spatial equilibriium problems formulated in this manner. As Zusman (1969) and Zusman and others (1969) point out, however, the symmetry conditions imposed by the Takayama and Judge (1964) formulation are a severe restriction, particularly in terms of the demand equations. Zusman (1969) questions the merits of formulating the spatial equilibrium problem as an extremum problem, given this restriction. Adams and

Haynes (in press) also discuss limits to the applicability of the Takayama and Judge (1964) formulation, and they provide a survey of some alternative approaches to formulating the maximization problem.

Reactive Programming

Tramel and Seale (1959) define "reactive programming" as a means of obtaining equilibrium values for prices, quantities, and trade flows given supply and demand functions (equations 1 and 2), and transportation costs (TC_{ijk}). Their approach has been termed a "market-simulating" procedure because the iterative means by which the equilibrium values are computed corresponds to the adjustment process in actual markets (Zusman and others 1969).

Reactive programming is a less restrictive method of obtaining the equilibrium solution to the spatial market problem than is quadratic programming because reactive programming requires only that the market adjustment process be stable (Zusman and others 1969). Stability (convergence to an equilibrium, such as q_e in fig. 1) is assured if supply equations do not slope downward and demand equations do not slope upward; that is, if supply and demand equations exhibit normal behavior. Supply and demand functions can have any (differentiable) form, and symmetry of cross-partial derivatives is not required (Zusman 1969). Zusman and others (1969) derive the formal conditions for stability.

There is no explicit objective function in the reactive programming algorithm as there is in Samuelson's (1952) solution method. In reactive programming, the market equilibrium is computed by adjusting production and shipments for each producer until no producer can increase net revenue by altering either output or the pattern of shipments. Given an initial set of shipments, reactive programming maximizes net revenue for one producer, in all markets, by holding production and shipments from other regions constant. Each producing region is examined in sequence, and this sequence is repeated until the equilibrium conditions are satisfied within the specified tolerance. The value of the (user-specified) tolerance is substituted for zero on the right side of equation (5).

Takayama and Judge (1963) refer to this iterative procedure as a "gradient" method and offer two major criticisms of it: first, that convergence to an equilibrium is not assured, and second, that an exact solution cannot be achieved in a finite number of iterations. Tramel (1965), Zusman and others (1969), and King and Ho (1972) offer counter arguments to both criticisms. Zusman and others (1969) argue that the stability of the market adjustment process ensures the convergence of a market-simulating computational procedure. Zusman (1969) also points out that the "stability approach," as illustrated by reactive programming, results in greater flexibility than the Takayama and Judge (1964) approach (it is applicable to a wider array of market conditions) with very little loss of analytical rigor.[1]

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[1] A direct comparison of reactive programming and quadratic programming is provided in appendix 1.

Tramel (1965) responds to the second criticism about an exact solution by conceding that reactive programming converges to a solution asymptotically, but he argues that this does not lead necessarily to excessively long computation time. He points out that shortcuts can be introduced to speed the solution process. King and Ho (1972) confirm Tramel's experience with solution times, and they introduce to the algorithm additional revisions designed to reduce solution time even further.

Reactive Programming Solution Procedure

The reactive programming algorithm was introduced by Tramel and Seale (1959). Tramel and Seale (1963) and Tramel (1965) describe the algorithm in more detail, including methods for reducing computing time. Many of these methods are used in the version of reactive programming described here, called REACTT. The general structure of reactive programming is illustrated in figure 2.

The procedure for computing an equilibrium begins at a basis that satisfies the shipments balance restrictions in equations (3) and (4). This starting point can be arbitrary, but the equilibrium solution can be computed faster by choosing the set of q_{ijk} that satisfies (3) and (4) and minimizes transportation costs (Tramel and Seale 1963).

To solve for flows that minimize transportation costs, total supply and demand quantities (and transportation costs) must be known. King and Ho (1972) compute the starting quantities by solving the supply and demand equations with the assumption that transportation costs are zero. In a multiperiod model, supply and demand totals from the previous period's solution can be used as initial estimates of PT_{ik} and X_{jk}.

In REACTT, starting quantities for supply and demand regions are read in as part of the data for the problem. These values may be more or less arbitrary, with the sole restriction that the sum of supplies must equal the sum of demands. An efficient starting basis for computing the market equilibrium is then found by solving:

$$\text{Minimize } \sum_i \sum_j \sum_k TC_{ijk} q_{ijk}; \tag{8}$$

subject to:

$$q_{ijk} \leq UUU_{ijk}, \tag{9}$$

$$q_{ijk} \geq LLL_{ijk}, \tag{10}$$

$$\sum_j q_{ijk} \leq PT_{ik}, \tag{11}$$

$$\sum_i q_{ijk} \geq X_{jk}, \text{ and} \tag{12}$$

$$q_{ijk} \geq 0 \text{ for all i, j, and k}; \tag{13}$$

where UUU_{ijk} is the upper limit on shipments of product k from supplier i to market j, LLL_{ijk} is the lower limit on these shipments, and the other terms are as defined earlier.

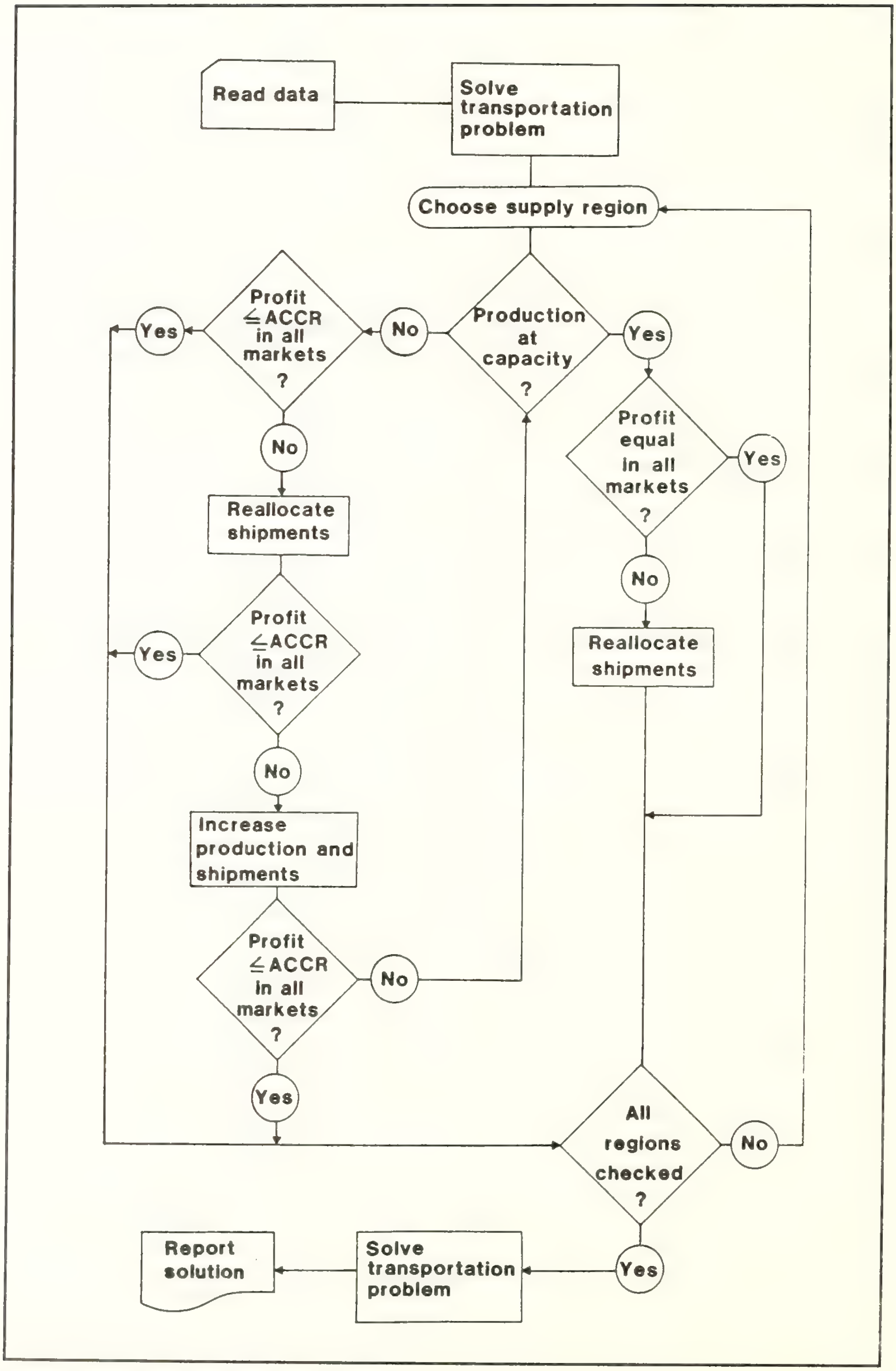
Read data
Solve transportation problem
Choose supply region
Production at capacity ?
No
Yes
Profit ≤ ACCR in all markets ?
Yes
No
Reallocate shipments
Profit ≤ ACCR in all markets ?
Yes
No
Increase production and shipments
Profit ≤ ACCR in all markets ?
No
Yes
Profit equal in all markets ?
Yes
No
Reallocate shipments
All regions checked ?
No
Yes
Solve transportation problem
Report solution

Figure 2—General structure of reactive programming.

The remainder of the reactive programming algorithm is summarized in the following steps, in this case for one supply region and one product:

1. Compute net price (excess profit) for shipments to each market and the quantity-weighted average profit for shipments to all markets (AVPN). If a region is operating at its capacity (an upper limit on production entered as data for the problem), then AVPN remains equal to the average profit in all markets. If production can be increased, AVPN is set equal to zero. Then for each market compute:

$$SKP_{jk} = P_{jk} - C_{ik} - TC_{ijk} - t_{ijk}C_{ik} - AVPN \,. \tag{14}$$

2. Using the solution tolerance (ACCR) in place of zero, check the equilibrium condition stated in equation (5) by comparing SKP_{jk} and ACCR. (Continue to the next market if flows are zero.) For any supply region operating at capacity, the comparison of SKP_{jk} from equation (14) and ACCR defines the equilibrium condition as equal excess profit in all markets. When production is not constrained, the equilibrium condition is that the absolute value of excess profits must be less than ACCR. If the equilibrium condition is not met, continue with the calculations for this supplier; if the condition is met, go to the next supply region.

3. Using the slope of the supply equation for this region (SLOPS) and the slope from the demand equation for each market ($SLOPD_j$) compute a new shipments quantity for each market using Newton's approximation:

$$S_{jk} = q_{ijk} - SKP_{jk}/(SLOPD_j - SLOPS) \,. \tag{15}$$

4. Compute the difference between the current supply from this region and the production capacity ($DIFF = PT_{ik} - PC_{ik}$, where PC_{ik} is the supply region capacity); compute the change in quantity demanded given a unit change in price ($R_{jk} = 1/SLOPD_{jk}$), for each market, and the total change for all markets (TOT). Compute a revised shipment to each market as:

$$S_{jk} = S_{jk} - (R_{jk}/TOT)\,DIFF. \tag{16}$$

5. Adjust the market total and compute the new market price for each market:

$$X_{jk} = X_{jk} - q_{ijk} + S_{jk} \text{ ; and} \tag{17}$$

$$P_{jk} = p\,(X_{jk}) \,. \tag{18}$$

6. Adjust the production total for this supplier and compute the new (marginal) cost:

$$PT_{ik} = \sum_j [PT_{ik} - q_{ijk} + S_{jk}] \text{ ; and} \tag{19}$$

$$C_{ik} = c(PT_{ik}) \,. \tag{20}$$

7. Go to the next supply region and repeat steps 1 through 6, and continue until the equilibrium condition (step 2) is satisfied for all supply regions (and products). This iterative procedure is continued until no producer can benefit from a change in the quantity produced or from a change in the pattern of shipments.

Tramel (1965) and King and Ho (1972) discuss several steps that can be used to improve the efficiency of the reactive programming algorithm. In addition to the use of linear programming to determine an efficient starting point, these steps include a series of checks to determine whether some or all the calculations are required in each iteration. These procedures are not shown in steps 1 through 7, but they have been retained in REACTT.

If supply from a region is fixed, equation (15) is simplified, and the problem is then one of allocating this (fixed) quantity to equate excess profit in all markets.When both supply and demand are fixed (in all regions) the spatial equilibrium problem is reduced to the transportation problem, equations (8) through (13). One illustration of the flexibility of reactive programming is its ability to solve a problem containing a mixture of price-responsiveness and nonprice-responsiveness (fixed quantities) in both supply and demand regions. There are also no restrictions on the functional forms of the supply and demand equations, other than the requirement that the slopes of equations (1) and (2) can be defined (for use in equation 15).

Applications of Reactive Programming

Tramel and Seale (1959) describe the reactive programming algorithm and illustrate its application with an analysis of the supply and demand for watermelons. Seale and Allen (1959) provide another example of an early use of the technique. More recent examples of reactive programming can be found in Riley and Blakely (1975) and Dahlgran (1980).

King and Ho (1972) document an "improved" version of the Tramel and Seale (1959) algorithm and provide sample problems to illustrate its use. The paper by King and Gunn (1981) is an update of King and Ho (1972) and provides additional examples of spatial problems that can be solved using reactive programming.

There are surprisingly few examples of the application of reactive programming to an analysis of trade and trade policies. Zusman and others (1969) elaborate on the algorithm described by Tramel and Seale (1959) and apply their solution procedure to an examination of the impact of alternative trade policies instituted by the European Economic Community. Gemmill (1977) conducts an analysis of world sugar markets and examines the impact of U.S. trade policies. Adams and Haynes (1980), Adams (1983), and Brooks (in press) use reactive programming to model forest products markets.

Revisions to King and Ho's Reactive Programming Code

King and Ho (1972) provide a detailed description of the reactive programming algorithm and include the "Tramel/NCSU" program written in FORTRAN. This program reflects some improvements on the algorithm described in detail by Tramel (1965), most notably the ability to solve a problem with two interdependent products and an efficient method for computing initial supply and demand quantities. The version of reactive programming described in this report is an extension of the King and Ho (1972) algorithm.[2] Technical differences between this and the King and Ho (1972) code will not be discussed in any detail because these changes will be of interest only to users of the original code and should be readily apparent to them.

Major revisions to the King and Ho (1972) algorithm will be described in some detail, however. The REACTT code contains the following, additional features:

1. Separate supply and demand regions are defined for all products.
2. Price interaction (in supply or demand) for up to five products can be examined.
3. Fixed demand regions can be included in the problem.
4. Ad valorem (import) tariffs can be specified for each product and every pair of supply and demand regions.
5. Upper and lower bounds can be specified for shipments along any route.

Regional definitions—In REACTT the spatial equilibrium for each product is computed separately, but the interaction between products in both supply and demand functions is still accounted for. In earlier versions of the algorithm (such as King and Ho 1972), supply and demand regions are defined as "product-regions," and flows of one product to another product's "region" are prevented by setting transportation costs very high. In REACTT, there is a single list of supply (demand) regions that includes producers (markets) for all products. If a region does not produce (consume) a particular product, the coefficients of its supply (demand) function are set to zero. The dimension of variable arrays in REACTT allows for the specification of as many as 20 producing regions and 20 markets.[3]

Price interaction—The supply and demand function coefficients specify the price (or cost) of each product as a function of an intercept, of its own quantity, and of the quantity of all other products. This relationship is stated in general terms in equations (1) and (2). As many as five products may be included in REACTT; previous versions of the algorithm were restricted to two products. If there is no interaction between products in supply or demand, in any region, a zero must be entered for the appropriate (quantity) coefficient.[4]

Fixed demand—The range of spatial equilibrium problems that can be solved using REACTT includes those in which one or more supply or demand regions do not respond to price changes. Previous versions of reactive programming included fixed supply regions; the treatment of fixed demand regions here is analogous. Supply and demand function data are entered in price-dependent form; functions are fixed when the coefficients for all quantity terms are zero and, in this case, the starting demand quantity is taken as the fixed requirement for that region (and product).[5] Flows to fixed demand regions are determined in initial solution of the transportation problem. Because the market price is undefined, or arbitrary (at least initially), fixed-demand regions are skipped during reactive programming computations that reallocate shipments. After an equilibrium has been computed, the price reported for a fixed demand region is the quantity-weighted average cost (including any tariffs) for shipments to that region.

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[2] King and Gunn (1981) also document a revised version of the program described by King and Ho (1972).

[3] The parameter MAXREG sets the maximum number of regions (either supply or demand); computer memory requirements can be minimized by adjusting this parameter to the size of the problem.

[4] See appendix 3 for a description of the structure of the data file for REACTT.

Import tariffs—All computations of excess profit (per unit) in REACTT take into consideration any ad valorem tariffs imposed by the market. Tariff data for each product is entered as a proportion, as part of the definition of the problem. A unique tariff rate can be specified for shipments from each possible supplier to each market. Tariffs can be computed on producer cost (customs basis) or be based on delivered cost (producer cost plus transportation cost). An integer variable (zero or one) is used to indicate the type of tariff computation appropriate for each market.

Flow bounds—In REACTT, the network allocation routine NETFLO, described by Kennington and Helgason (1980), is used in place of the linear programming subroutine described by King and Ho (1972).[6] An important feature added by NETFLO is the ability to specify upper and lower bounds on shipments. In principle, shipments from any supplier to any market can be specified exactly by setting the upper and lower bounds equal. Caution must be exercised when imposing flow constraints, however; difficulties may arise because of the structure of REACTT or because of the nature of the problem.

The structure of the solution in REACTT is shown in figure 2. The transportation problem is solved first (by using NETFLO) to establish a starting basis for the reactive programming computations. Supply and demand totals are revised in the reactive programming computations, after which NETFLO is used to compute the final shipments pattern. If no constraints are placed on shipments, the second solution of the transportation problem is redundant because the equilibrium solution (for competitive markets) will minimize transportation costs (Samuelson 1952, Seale and Tramel 1963). An infeasible problem is created when producer (or market) adjustments result in quantities that conflict with the flow constraints. An example of such a conflict is total market demand that is less than a minimum flow from a single producer.

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[5] The intercept term is taken as the initial value for market price and is displayed in any intermediate reports.

[6] The expansion of the reactive programming code to five products and the inclusion of NETFLO are described in J. L. Arthur and B. A. McCarl, "Extensions and modifications of the reactive programming algorithm of King and Ho," unpublished manuscript on file at the Pacific Northwest Research Station, Macroeconomics of U.S. and International Trade Project, Portland, Oregon.

Infeasible flow constraints will cause a program error (see table 3, appendix); the only possible correction is to relax the constraint(s) until the problem becomes feasible.[7] Kennington and Helgason (1980) provide a more detailed description of NETFLO and include a listing of the program.

Some other changes to King and Ho's (1972) code should be noted as well. Only one functional form (linear) has been included for supply and demand functions in REACTT; the code (in appendix 6) is annotated to indicate where changes must be made in order to use different functional forms. Any differentiable functional form can be used for either supply or demand functions; functional forms can differ between regions for supply or demand. These modifications require only that slopes, prices, and costs be (re)defined appropriately, and for mixed functional forms, that careful attention be paid to the indexes that refer to particular supply and demand regions.

The code for REACTT is divided into five subroutines (plus one program segment) that facilitate incorporation into a larger market simulation model, if desired. The general structure of a multiperiod simulation model using REACTT is illustrated in figure 3. The Timber Assessment Market Model (Adams and Haynes 1980) provides one example of how the reactive programming routines can be incorporated into such a model system.[8] Program segment REACTT provides the structure for the solution process and would be replaced (or expanded) in any multiperiod market simulation model. Subroutine DATAIN is used to enter the data for this single solution of the spatial equilibrium problem. Subroutine REACT contains the core of the reactive programming calculations; subroutine REPORT provides reports on intermediate results and reports the equilibrium solution. Subroutines SETUP and NETFLO are used to solve the network allocation problem.

The source code for REACTT is written in the American National Standards Institute (ANSI) FORTRAN 77 language. This code has been compiled and tested on a Control Data Corporation[9] (CDC) Cyber 170/720-2 computer at Oregon State University, Corvallis. With the possible exception of the function calls for the date and time, all statements should compile on any system supporting ANSI-standard FORTRAN.

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[7] The equilibrium solution computed in subroutine REACT is "lost" when an infeasible linear programming problem is encountered because all flows (q_{ijk}) are set to zero before the attempt to solve the transportation problem.

[8] For more detail on the structure of TAMM, see D. Adams, J. Gourley, and R. Haynes, "Timber Assessment Market Model: user's guide," unpublished manuscript on file at the Pacific Northwest Research Station, Macroeconomics of U.S. and International Trade Project, Portland, Oregon.

[9] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the Department of Agriculture of any product or service to the exclusion of others that may be suitable.

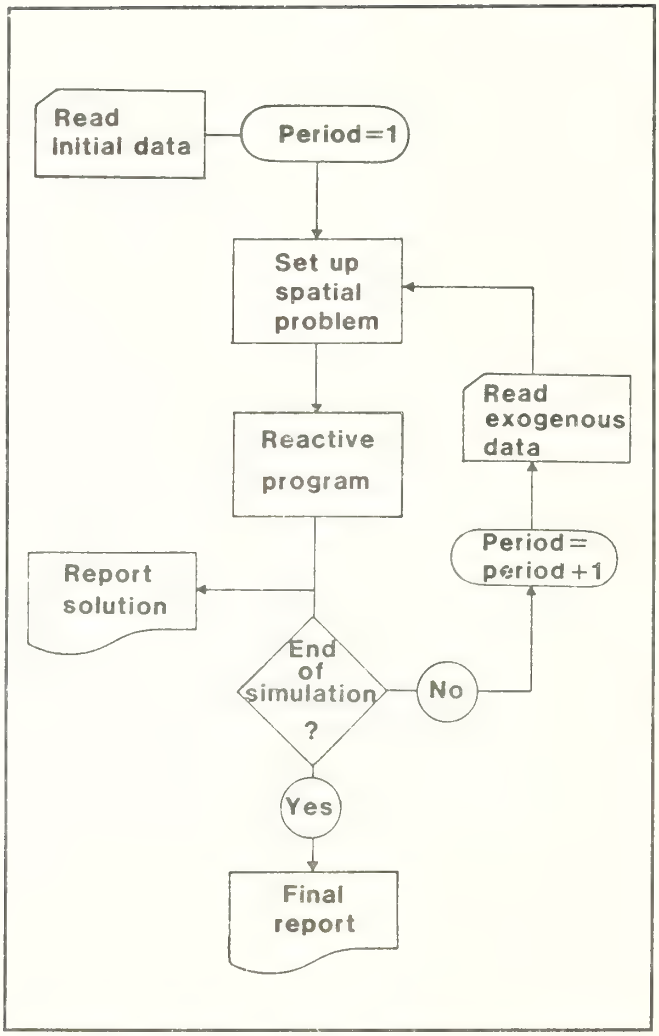

Figure 3—An example of multiperiod market simulation using reactive programming.

Source code and sample data sets can be supplied (at cost) on IBM-compatible diskettes or on magnetic tape. Those interested in obtaining a copy should contact the authors.

This code has also been compiled and executed on IBM-compatible microcomputers. In general, although with exceptions, microcomputer results are comparable to mainframe computer results; supply prices and market prices will differ by an amount less than the solution tolerance. The microcomputer solution will require more iterations than does the mainframe version of REACTT. Some problems arise with the microcomputer version of REACTT; most can be traced to internal precision. Scaling factors must be reduced (to 1.0) to solve the network allocation problem; other, minor modifications to the code may be required as well.

Extensions to REACTT

The modifications to Tramel and Seale's (1959) reactive programming algorithm shown here do not exhaust the possibilities for revisions or enhancements to this computational procedure. The algorithm can be used to compute spatial equilibria using both a variety of functional forms and a mixture of functional forms for supply and demand equations. The REACTT code can be easily modified to accommodate this. Another extension to this code would be the addition of export tariffs or subsidies. This is analogous to the import tariffs included here. Where supply and demand equations (costs and prices) are denominated in different currencies, the rate of exchange can be added to the calculation of excess profit in equation (14).

Adams (1983) describes a spatial equilibrium problem that involves two market levels (trade in raw materials and processed products) and interdependent prices (costs). He solves each market level problem using reactive programming and an iterative procedure to link the two solutions. That is, one market equilibrium is solved using a guess at prices in the other market; the resulting prices are used in the solution of the remaining market problem. Successive substitution of prices between markets leads to convergence to an overall equilibrium. In principle, this procedure can be used to link any number of market levels in either a recursive or a cascading structure. Brooks (in press) uses the reactive programming code reported here and this iterative procedure to solve for spatial equilibrium in two linked markets.

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Appendix 1: A Comparison of Reactive and Quadratic Programming

A data set similar to that shown in appendix 4 was used to compare the reactive programming algorithm REACTT, and the quadratic programming algorithm SEBEND (McCarl and others 1984). The sample problem has seven supply regions, six demand regions, and two products; the slope coefficients of both supply and demand equations are symmetric (as required by quadratic programming). Both algorithms were compiled and run using a CDC Cyber 170/720-2 computer, and in both cases the output option chosen was to echo the problem data and report only the final solution.

The reactive programming solution required 3.036 CP seconds; the quadratic programming solution required 3.347 CP seconds. Table 1 compares price and quantity data reported by both models, for one product (lumber). The solution tolerance in REACTT was set at 2000; no price reported by REACTT differs from the SEBEND price by more than this amount. Supply region and market quantities are also substantially the same. Data for the second product are similar.

Table 1—A comparison of REACTT and SEBEND

Supply region prices			Market prices		
Region	REACTT	SEBEND	Market	REACTT	SEBEND
WW	160200.9	159920.8	NW	164828.9	164510.8
WE	163507.4	162030.8	SW	178574.8	176740.8
SW	166746.4	165020.8	RK	174267.2	175260.8
RM	165087.1	166150.8	NC	189720.6	189580.8
SC	177983.2	179830.8	NE	190893.9	191980.8
SE	177373.9	178460.8	SO	188755.1	189390.8
CA	158104.3	158113.4			

Supply region quantities			Market quantities		
Region	REACTT	SEBEND	Market	REACTT	SEBEND
WW	6313.5	6311.7	NW	2551.0	2552.2
WE	2659.1	2643.1	SW	9294.1	9320.2
SW	6338.8	6325.5	RK	2483.5	2478.7
RM	3624.9	3633.2	NC	9948.3	9951.1
SC	8578.9	8592.9	NE	3123.0	3114.8
SE	7393.0	7401.5	SO	12970.2	12954.1
CA	5462.1	5463.1			
TOTAL	40370.2	40371.1		40370.2	40371.1

Appendix 2: REACTT Variable Definitions

This appendix provides definitions of variables used in Program REACTT, and subroutines REACT, REPORT, and DATAIN. The reader is directed to Kennington and Helgason (1980) and Helgason and Kennington (1979) for more information on NETFLO.

Variable	Definition
ACCR	Solution tolerance, defined as the amount by which excess profits (for any supplier in any market) may differ from zero (must be scaled to supply and demand equations)
AVPN	The average net price (profit) for the current supply region in the current iteration AVPN = SUM/CNT; AVPN is set=0 if the supply region production total (PT(I,K)) is less than capacity (PC(I,K))
BIG	Sufficiently large number, used to indicate no flow in NETFLO
C(I,K)	Cost, supply region I, product K
CNT	The total quantity shipped to all markets by the current supply region in the current iteration
CPAY	Consumer outlay in each market
CPT	Total consumer outlay, all markets
DEMAND(N,J,K)	Price-dependent demand equation coefficients; N=1 is the intercept, N=2 to N=NPROD+1 are the coefficients for the quantity of the first through the NPROD th products (for each I and K)
DIFF	The difference between PROT and capacity for the supply region (PC(I,K))
DUMP	Integer variable that determines the quantity of output (see table 2)
EPS	Parameter sufficiently close to zero
FINIS	Integer flag that defines when the RP iteration is completed; when FINIS =5, the iteration continues; FINIS=0 indicates an equilibrium solution; FINIS is set=0 at the start of each iteration, and set=5 if net price is greater than ACCR (in absolute value) in any market, for any supply region
FLWSCL	Scaling parameter for flows in NETFLO
IFAS(I)	Integer flag used to indicate whether to skip supply region I in the current iteration; IFAS is set equal to 1 (skip this region) when the equilibrium conditions are met; IFAS is reset to 0 on a cycle determined by ITEST
INDIC	Integer flag used to indicate the need for a recalculation within an RP iteration; INDIC is set=0 to start, then set=5 if S(J,K) has been set arbitrarily because the initial S(J,K) was less than or equal to zero; when INDIC=5 a new total supply and residual supply is computed, and a new S(J,K) is computed for each market
ISP(I,K)	Implicit supply price: for each supply region (and product) this is computed as the greatest difference between price (in any market) and transportation cost (plus tariffs); for supply regions operating below capacity ISP(I,K)=C(I,K)± ACCR; otherwise ISP indicates the “profit potential” in the absence of the capacity (or flow) constraint

Variable	Definition
ITEST	Integer counter that defines the cycle for setting the flag IFAS(I,K) = 0; every ITEST RP iterations the flag is set to 0 and all supply regions are examined for possible improvements to the supply total or shipments pattern (regions are skipped when there is no change from the previous iteration)
IX(I,K)	Integer flag used to indicate a fixed supply region for this product (IX(I,K) = 0) or marginal cost varying with quantity (IX(I,K) = 1)
JX(J,K)	Integer flag used to indicate a fixed demand region for this product (JX(J,K) = 0) or price varying with quantity demanded (JX(J,K) = 1)
LINMAX	Maximum number of lines per page (output file)
LLL(I,J,K)	Lower bound on shipments of product K from I to J
MAXIT	Maximum number of reactive programming iterations
NDEM	Number of product demand regions (markets)
NLIN	Number of lines printed, current page (output file)
NLPIT	The number of NETFLO iterations
NOLD	The total number of RP iterations
NPAGE	Page number (output file)
NPROD	Number of products
NRPIT	The number of the current RP iteration
NSUP	Number of product supply regions
OBJSCL	Scaling parameter for the objective function in NETFLO
P(J,K)	Price, demand region J, product K
PA(I,K)	Production allocation for supply region I, in the current RP iteration
PAT	Total quantity supplied, all producers
PC(I,K)	Production capacity, supply region I, product K
PREV(I)	Producer revenue, supply region I
PRINTS	Integer counter used to determine the cycle for intermediate reports
PROD(K)	3-character identifier of products (K=1, NPROD)
PROT	The total supply for the current supply region in the current iteration (the sum of flows to all markets)
PRT	Total producer revenue, all producers
PT(I,K)	Production total, supply region I, product K
Q(I,J,K)	Quantity of product K shipped from I to J
QST	The total quantity shipped, all producers, all markets
R(J,K)	The inverse of the slope of the demand function; that is, (1/DEMAND(K+1,J,K))

Variable	Definition
RDATE	Date of the current run (system-defined)
REGDEM(J)	2-character identifier of demand regions (J=1, NDEM)
REGSUP(I)	2-character identifier of supply regions (I=1, NSUP)
RTIME	Time of the current run (system-defined)
RUNERR	Integer variable used to indicate that an error has occurred (when greater than 0) and its location (see table 3)
S(J,K)	Trial quantity for shipments of K from the current supply region to market J
SC	The shipping cost for flows Q(I,J,K)TC(I,J,K)
SCT	Total shipping cost, all producers, all markets
SKP	The deviation of net price in a market from the average net price in all markets (AVPN), for the current supply region in the current iteration; SKP is compared to ACCR (for each supply region, all markets) to determine if an equlibrium has been reached for this supplier
SUM	The total profit (net price times quantity) in all markets for the current supply region in the current iteration
SUPPLY(N,I,K)	Cost-dependent supply equation coefficients; N=1 is the intercept, N=2 to N=NPROD+1 are the coefficients for the quantity of the first through the NPRODth products (for each I and K)
TAR	The tariff collected on flows Q(I,J,K)
TARIF	The total tariff collected in each market
TARIFF(I,J,K)	Ad valorem tariff (expressed as a proportion) imposed by market J on shipments of product K from supply region I
TC(I,J,K)	Transportation cost for shipments of product K from I to J
TFLAG(J)	Integer flag indicating the type of tariff computation for market J; TFLAG=0 indicates tariff assessed on the "customs price" (producer cost only); TFLAG=1 indicates tariff assessed on producer cost plus transportation cost
TITLE	80-character description of the data set, used as a heading on each page of output
UUU(I,J,K)	Upper bound on shipments of product K from I to J
X(J,K)	Total quantity demanded, market J, product K
XJT	Total quantity demanded, all markets

Table 2—REACTT documentation options[1]

DUMP	Output
0	None[2]
1	Final report
2	+ data echo
3	+ intermediate reports
4	+ SETUP reports[3]
5	+ NETFLO reports[3]

[1] Reports are cumulative.

[2] For use when REACTT is included as a set of subroutines in a larger simulation model.

[3] See Helgason and Kennington (1979) for more information.

Table 3—REACTT error messages[1]

NSTOP	Subroutine	Problem
10	SETUP	Infeasible problem: net requirements are negative
20	SETUP	Too many arcs
30	SETUP	Too many arcs
40	SETUP	Too many arcs
50	NETFLO	Too many arcs
60	NETFLO	Infeasible problem: net requirements are negative (induced by lower bounds on arcs flows)
70	NETFLO	Infeasible: artificial variables in basis

[1] These errors originate in the network allocation subroutines. The value of RUNERR is reported when abnormal termination occurs, where RUNERR = NSTOP + NPROD (the number of the current product at the time of the error). Two additional error messages can occur in REACTT: an "illegal end of file encountered" while reading input; and "illegal data encountered" (too many regions or too many products).

Appendix 3: REACTT Data File Structure

Data for REACTT is read from file DATA by subroutine DATAIN called by program REACTT. File DATA contains three sections: (1) parameter information; (2) alphanumeric data identifying regions and products; and (3) blocks containing the supply and demand functions, transportation costs, tariffs, flow bounds, capacities, and starting values (one block for each product). The sequence of data entry is shown below; a sample data set is included as appendix 4.

1. Parameter information
   TITLE (80-character title of the data set)
   DESC (80-character description)
   NSUP, NDEM, NPROD, DUMP, ACCR
   DESC (80-character description)
   FLWSCL, OBJSCL, BIG, MAXIT

2. Alphanumeric data identifying regions and products
   (REGSUP(I), I=1,NSUP)
   (REGDEM(J), J=1,NDEM)
   (PROD(K), K=1,NPROD)

3. Product data blocks (K=1,NPROD)
   DESC (80-character description)
   ((SUPPLY(N,I,K), N=1,NPROD+1), I=1,NSUP) (1 line for each region)
   DESC
   ((DEMAND(N,J,K), N=1,NPROD+1), J=1,NDEM) (1 line for each region)
   DESC
   (TFLAG(J), J=1,NDEM)
   DESC
   ((TC(I,J,K), I=1,NSUP), J=1,NDEM) (1 line for each demand region)
   DESC
   ((TARIFF(I,J,K), I=1,NSUP), J=1,NDEM) (1 line for each market)
   DESC
   ((LLL(I,J,K), I=1,NSUP), J=1,NDEM) (1 line for each market)
   DESC
   ((UUU(I,J,K), I=1,NSUP), J=1,NDEM) (1 line for each market)
   DESC
   (PT(I,K), I=1,NSUP)
   DESC
   (PC(I,K), I=1,NSUP)
   DESC

Appendix 4: REACTT Example Data Set

```
LR 28   1977 85/01/10. 21.07.34. 2ND SOUTHERN TIMBER SUPPLY STUDY RUN
NUMBER OF SUPPLY AND DEMAND REGIONS AND PRODUCTS, DUMP FLAG AND ACCURACY
7 6 2   2 2000.
SCALING FACTORS FLWSCL, OBJSCL, BIG, MAXIT
1000.0 1000.0 1000000000. 20
WW     WE     SW     RM     SC     SE     CA
NW     SW     RK     NC     NE     SO
LUM    PLY
LUMBER SUPPLY EQUATIONS
-339669.3370             56.7995                2.1130
-133615.0350            105.8041               10.0439
-470226.3518            128.3077               13.0189
-520796.5081            139.7448                9.9400
-481186.5530            124.9247                6.1589
-314040.1351            130.0521                7.3081
     3877.0887             8.6149                .0000
LUMBER DEMAND EQUATIONS
483616.4233           -124.7632                .0000
531053.5767            -55.1405                .0000
484494.0686           -180.8876                .0000
488194.6525            -31.4651                .0000
448538.7186            -80.9404                .0000
493826.8126            -31.6092                .0000
LUMBER TARIFF COMPUTATION FLAGS
0.0        0.0        0.0        0.0        0.0        0.0
LUMBER TRANSPORTATION COSTS
 4590       5370      10490      14590      29610      31920      10120
16820      16520      11720      18050      29400      31920      19720
16160      14430      17090       9110      26180      28710      18810
29660      27550      28330      23430      15160      17470      27250
34870      32550      33310      31770      20060      13520      31250
29470      27520      28150      24100       9560      10930      30050
LUMBER TARIFF RATES
0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000     0.000
LUMBER LOWER BOUND ON FLOWS
0           0           0           0           0           0           0
0           0           0           0           0           0           0
0           0           0           0           0           0           0
0           0           0           0           0           0           0
0           0           0           0           0           0           0
0           0           0           0           0           0           0
LUMBER UPPER BOUND ON FLOWS
1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6
1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6
1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6
1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6
1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6
1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6     1.0E6
LUMBER SUPPLY STARTING VALUES
7665.00     2426.552   4961.484   4579.00     4633.00     3358.024   10429.00
LUMBER SUPPLY MAXIMA
8116.188    2427.552   4962.484   4669.720   4782.032    3359.0240  10924.00
LUMBER DEMAND STARTING VALUES
2869.8563    7075.6464    1999.4901  11204.0053    3749.0439  11154.0181
```

```
PLYWOOD  SUPPLY  EQUATIONS
-118164.4792               1.9885              20.9886
-151974.4715              10.7045             217.9148
  -58534.5107             11.2239             218.1315
-225886.7596              11.1675             208.6711
-308655.9183               8.0967              65.7917
-521450.4822               9.6075             306.3367
           .0000                   .0000                    .0000
PLYWOOD  DEMAND  EQUATIONS
340038.8474                  .0000            -112.9010
231640.6753                  .0000             -56.3961
543402.9341                  .0000            -421.4998
218041.3847                  .0000             -27.8647
222725.4516                  .0000             -51.2988
271838.7707                  .0000             -29.7372
TARIFF  COMPUTATION  FLAG
0.0        0.0        0.0        0.0        0.0        0.0
PLYWOOD  TRANSPORTATION  COSTS
  2410      2550      4990      6930     15660     16880  1000000
  8820      7850      5570      8580     15540     16880  1000000
  8890      6860      8120      4330     13840     15180  1000000
15550     13100     13470     11130      7990      9250  1000000
18280     15470     15840     15100     10650      7250  1000000
15450     13030     13380     11450      5550      6440  1000000
PLYWOOD  TARIFF  RATES
0.000    0.000    0.000    0.000    0.000    0.000    0.000
0.000    0.000    0.000    0.000    0.000    0.000    0.000
0.000    0.000    0.000    0.000    0.000    0.000    0.000
0.000    0.000    0.000    0.000    0.000    0.000    0.000
0.000    0.000    0.000    0.000    0.000    0.000    0.000
0.000    0.000    0.000    0.000    0.000    0.000    0.000
PLYWOOD  LOWER  BOUND  ON  FLOWS
0          0          0          0          0          0          0
0          0          0          0          0          0          0
0          0          0          0          0          0          0
0          0          0          0          0          0          0
0          0          0          0          0          0          0
0          0          0          0          0          0          0
PLYWOOD  UPPER  BOUND  ON  FLOWS
1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6
1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6
1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6
1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6
1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6
1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6
PLYWOOD  SUPPLY  STARTING  VALUES
9509.00    1115.00      915.00    1327.00     5115.00     1705.00     0.00
PLYWOOD  SUPPLY  MAXIMA
.10E+06   .10E+06   .10E+06   .10E+06   .10E+06   .10E+06   .10E+06
PLYWOOD  DEMAND  STARTING  VALUES
2271.0000   2628.0000   1082.0000   4803.0000   2673.0000   6229.0000
```

Appendix 5: REACTT Example Output

This appendix is the output from two runs of REACTT. In both cases, the output option chosen echos the problem data and reports only the final equilibrium solution.

The first run uses data as shown in appendix 4. The second run uses the same data, except that a 30-percent tariff is imposed by all markets on shipments of lumber (product 1) from Canada (supply region CA).

Run 1 (No Tariffs)

```
LR     28 -- 1977  85/01/10.  21.07.34.  2ND  SOUTHERN  TIMBER  SUPPLY  STUDY  RUN      86/04/21.  13.21.45.  PAGE  1    REACTT
NUMBER  OF  SUPPLY  AND  DEMAND  REGIONS  AND  PRODUCTS,  DUMP  FLAG  AND  ACCURACY
                   7  SUPPLY  REGIONS
                   6  DEMAND  REGIONS
                   2  PRODUCTS
                   DIAGNOSTIC  OUTPUT  LEVEL    2
                   REACTIVE  PROGRAMMING  ACCURACY  =      2000.000
                   FLWSCL=                     1000.
                   OBJSCL=                    1000.
                   BIG      =          1000000000.

                     PRODUCT     1      LUM      LUMBER   SUPPLY   EQUATIONS
                                       INTERCEPT      LUM  COEFFICIENT      PLY  COEFFICIENT
      WW                              -339669.337                56.800                 2.113
      WE                              -133615.035               105.804                10.044
      SW                              -470226.352               128.308                13.019
      RM                              -520796.508               139.745                 9.940
      SC                              -481186.553               124.925                 6.159
      SE                              -314040.135               130.052                 7.308
      CA                                 3877.089                 8.615                  .000
                     PRODUCT     1      LUM      LUMBER   DEMAND   EQUATIONS
                                       INTERCEPT      LUM  COEFFICIENT      PLY  COEFFICIENT
      NW                               483616.423              -124.763                  .000
      SW                               531053.577               -55.141                  .000
      RK                               484494.069              -180.888                  .000
      NC                               488194.653               -31.465                  .000
      NE                               448538.719               -80.940                  .000
      SO                               493826.813               -31.609                  .000
                     PRODUCT     1      LUM      LUMBER   TARIFF   COMPUTATION   FLAGS
                                  NW               SW               RK               NC               NE               SO
      FLAG                         0                0                0                0                0                0
                     PRODUCT     1      LUM      LUMBER   TRANSPORTATION   COSTS
                            WW          WE          SW          RM          SC          SE          CA
      NW                 4590.       5370.      10490.      14590.      29610.      31920.      10120.
      SW                16820.      16520.      11720.      18050.      29400.      31920.      19720.
      RK                16160.      14430.      17090.       9110.      26180.      28710.      18810.
      NC                29660.      27550.      28330.      23430.      15160.      17470.      27250.
      NE                34870.      32550.      33310.      31770.      20060.      13520.      31250.
      SO                29470.      27520.      28150.      24100.       9560.      10930.      30050.
                     PRODUCT     1      LUM      LUMBER   TARIFF   RATES
                            WW          WE          SW          RM          SC          SE          CA
      NW                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
      SW                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
      RK                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
      NC                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
      NE                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
      SO                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
                     PRODUCT     1      LUM      LUMBER   LOWER   BOUND   ON   FLOWS
                            WW          WE          SW          RM          SC          SE          CA
      NW                    0.          0.          0.          0.          0.          0.          0.
      SW                    0.          0.          0.          0.          0.          0.          0.
      RK                    0.          0.          0.          0.          0.          0.          0.
      NC                    0.          0.          0.          0.          0.          0.          0.
      NE                    0.          0.          0.          0.          0.          0.          0.
      SO                    0.          0.          0.          0.          0.          0.          0.
                     PRODUCT     1      LUM      LUMBER   UPPER   BOUND   ON   FLOWS
                            WW          WE          SW          RM          SC          SE          CA
      NW             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
      SW             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
      RK             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
      NC             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
      NE             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
      SO             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
                     PRODUCT     1      LUM      LUMBER   SUPPLY   STARTING   VALUES
                     WW          WE            SW            RM         SC         SE          CA
                     7665.       2427.         4961.         4579.      4633.      3358.       10429.
                     PRODUCT     1      LUM      LUMBER   SUPPLY   MAXIMA
                     WW          WE            SW            RM         SC         SE          CA
                     8116.       2428.         4962.         4670.      4782.      3359.       10924.
                     PRODUCT     1      LUM      LUMBER   DEMAND   STARTING   VALUES
                     NW          SW            RK         NC         NE          SO
                     2870.       7076.         1999.      11204.     3749.       11154.
```

```
LR      28 -- 1977  85/01/10.  21.07.34.  2ND  SOUTHERN  TIMBER  SUPPLY  STUDY  RUN    86/04/21  13.21.45.    PAGE  2    REACTT
                    PRODUCT    2       PLY     PLYWOOD  SUPPLY  EQUATIONS
                                   INTERCEPT       LUM  COEFFICIENT      PLY  COEFFICIENT
   WW                             -118164.479                 1.989                20.989
   WE                             -151974.472                10.705               217.915
   SW                              -58534.511                11.224               218.132
   RM                             -225886.760                11.168               208.671
   SC                             -308655.918                 8.097                65.792
   SE                             -521450.482                 9.608               306.337
   CA                                    .000                  .000                  .000
                    PRODUCT    2       PLY     PLYWOOD  DEMAND  EQUATIONS
                                   INTERCEPT       LUM  COEFFICIENT      PLY  COEFFICIENT
   NW                              340038.847                  .000              -112.901
   SW                              231640.675                  .000               -56.396
   RK                              543402.934                  .000              -421.500
   NC                              218041.385                  .000               -27.865
   NE                              222725.452                  .000               -51.299
   SO                              271838.771                  .000               -29.737
                    PRODUCT    2       PLY      TARIFF  COMPUTATION  FLAG
                               NW              SW               RK               NC               NE               SO
   FLAG                         0               0                0                0                0                0
                    PRODUCT    2       PLY     PLYWOOD  TRANSPORTATION  COSTS
                         WW          WE          SW          RM          SC          SE          CA
   NW                 2410.       2550.       4990.       6930.      15660.      16880.    1000000.
   SW                 8820.       7850.       5570.       8580.      15540.      16880.    1000000.
   RK                 8890.       6860.       8120.       4330.      13840.      15180.    1000000.
   NC                15550.      13100.      13470.      11130.       7990.       9250.    1000000.
   NE                18280.      15470.      15840.      15100.      10650.       7250.    1000000.
   SO                15450.      13030.      13380.      11450.       5550.       6440.    1000000.
                    PRODUCT    2       PLY     PLYWOOD  TARIFF  RATES
                         WW          WE          SW          RM          SC          SE          CA
   NW                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
   SW                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
   RK                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
   NC                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
   NE                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
   SO                 .0000       .0000       .0000       .0000       .0000       .0000       .0000
                    PRODUCT    2       PLY     PLYWOOD  LOWER  BOUND  ON  FLOWS
                         WW          WE          SW          RM          SC          SE          CA
   NW                    0.          0.          0.          0.          0.          0.          0.
   SW                    0.          0.          0.          0.          0.          0.          0.
   RK                    0.          0.          0.          0.          0.          0.          0.
   NC                    0.          0.          0.          0.          0.          0.          0.
   NE                    0.          0.          0.          0.          0.          0.          0.
   SO                    0.          0.          0.          0.          0.          0.          0.
                    PRODUCT    2       PLY     PLYWOOD  UPPER  BOUND  ON  FLOWS
                         WW          WE          SW          RM          SC          SE          CA
   NW              .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
   SW              .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
   RK              .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
   NC              .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
   NE              .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
   SO              .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
                    PRODUCT    2       PLY     PLYWOOD  SUPPLY  STARTING  VALUES
                    WW        WE          SW          RM          SC          SE          CA
                    9509.     1115.       915.        1327.       5115.       1705.       0.
                    PRODUCT    2       PLY     PLYWOOD  SUPPLY  MAXIMA
                    WW        WE          SW          RM          SC          SE          CA
                 100000.   100000.     100000.     100000.     100000.     100000.     100000.
                    PRODUCT    2       PLY     PLYWOOD  DEMAND  STARTING  VALUES
                    NW        SW          RK          NC          NE          SO
                    2271.     2628.       1082.       4803.       2673.       6229.
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LR      28 -- 1977  85/01/10.  21.07.34.  2ND  SOUTHERN  TIMBER  SUPPLY  STUDY  RUN        86/04/21.  13.21.45.    PAGE  3  REACTT
               FINAL  REPORT          DUMP    2          LP  ITERATIONS     2          TOTAL  RP  ITERATIONS    11
                 ACCURACY      2000.000          SCALE  FACTORS  FLWSCL,  OBJSCL,  AND  BIG      1000.     1000.  1000000000
               COMMODITY  LUM

PRODUCING  REGION  SUMMARY
                         MAX.  Q.            QUANTITY            SUPPLY           IMPLICIT              PRODUCER
         IDENT.          SUPPLIED            SUPPLIED             PRICE       SUPPLY  PRICE              REVENUE
         WW             8116.1880           7684.8730       115179.7144         116554.6112         885141477.54
         WE             2427.5520           2274.4730       116686.9547         117129.3365         265401327.91
         SW             4962.4840           4578.9150       122735.3291         121654.6112         561994639.50
         RM             4669.7200           4487.4520       118769.6386         120549.3365         532973052.36
         SC             4782.0320           4667.6500       135603.9633         135089.3365         632951839.11
         SE             3359.0240           3325.4530       132206.7506         130339.2226         439647335.32
         CA            10924.0000          10923.9990        97986.2477         113755.7185        1070401671.73

         ALL                               37942.8150                                              4388511343.47

  MARKET  SUMMARY
                           QUANTITY              MARKET           CONSUMER             TARIFF
         IDENT.            DEMANDED               PRICE             OUTLAY          COLLECTED
         NW               2914.1980         120031.7554       349796301.48                .00
         SW               7212.1030         133374.6112       961911433.76                .00
         RK               1971.4690         127879.7727       252111007.64                .00
         NC              11034.0960         141005.7185      1555870633.93                .00
         NE               3764.2450         143859.2226       541521359.38                .00
         SO              11046.7040         144649.3365      1597898404.37                .00

         ALL             37942.8150                          5259109140.57

TRADE  FLOWS  AND  OPPORTUNITY  COSTS
                                      QUANTITY       OPPORTUNITY       TRANSFER        SHIPPING              TARIFF
  SOURCE       DESTINATION             SHIPPED              COST           COST            COST                COST
    WW               NW              2914.1980          262.0410        4590.00     13376168.82                 .00
    WW               SW              2633.1880         1374.8968       16820.00     44290222.16                 .00
    WW               RK                  .0000        -3459.9417       16160.00             .00                 .00
    WW               NC                  .0000        -3833.9960       29660.00             .00                 .00
    WW               NE                  .0000        -6190.4918       34870.00             .00                 .00
    WW               SO              2137.4870          -.3779         29470.00     62991741.89                 .00
    WE               NW                  .0000        -2025.1993        5370.00             .00                 .00
    WE               SW                  .0000          167.6565       16520.00             .00                 .00
    WE               RK                  .0000        -3237.1820       14430.00             .00                 .00
    WE               NC                  .0000        -3231.2362       27550.00             .00                 .00
    WE               NE                  .0000        -5377.7321       32550.00             .00                 .00
    WE               SO              2274.4730          442.3818       27520.00     62593496.96                 .00
    SW               NW                  .0000       -13193.5737       10490.00             .00                 .00
    SW               SW              4578.9150        -1080.7179       11720.00     53664883.80                 .00
    SW               RK                  .0000       -11945.5564       17090.00             .00                 .00
    SW               NC                  .0000       -10059.6107       28330.00             .00                 .00
    SW               NE                  .0000       -12186.1065       33310.00             .00                 .00
    SW               SO                  .0000        -6235.9926       28150.00             .00                 .00
    RM               NW                  .0000       -13327.8832       14590.00             .00                 .00
    RM               SW                  .0000        -3445.0274       18050.00             .00                 .00
    RM               RK              1971.4690             .1341        9110.00     17960082.59                 .00
    RM               NC               548.8890        -1193.9202       23430.00     12860469.27                 .00
    RM               NE                  .0000        -6680.4160       31770.00             .00                 .00
    RM               SO              1967.0940         1779.6979       24100.00     47406965.40                 .00
    SC               NW                  .0000       -45182.2079       29610.00             .00                 .00
    SC               SW                  .0000       -31629.3520       29400.00             .00                 .00
    SC               RK                  .0000       -33904.1905       26180.00             .00                 .00
    SC               NC                  .0000        -9758.2448       15160.00             .00                 .00
    SC               NE                  .0000       -11804.7407       20060.00             .00                 .00
    SC               SO              4667.6500         -514.6267        9560.00     44622734.00                 .00
    SE               NW                  .0000       -44094.9952       31920.00             .00                 .00
    SE               SW                  .0000       -30752.1393       31920.00             .00                 .00
    SE               RK                  .0000       -33036.9779       28710.00             .00                 .00
    SE               NC                  .0000        -8671.0321       17470.00             .00                 .00
    SE               NE              3325.4530        -1867.5280       13520.00     44960124.56                 .00
    SE               SO                  .0000         1512.5859       10930.00             .00                 .00
    CA               NW                  .0000        11925.5077       10120.00             .00                 .00
    CA               SW                  .0000        15668.3635       19720.00             .00                 .00
    CA               RK                  .0000        11083.5250       18810.00             .00                 .00
    CA               NC             10485.2070        15769.4708       27250.00    285721890.75                 .00
    CA               NE               438.7920        14622.9749       31250.00     13712250.00                 .00
    CA               SO                  .0000        16613.0888       30050.00             .00                 .00

     ALL                            37942.8150                                    704161030.20
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LR     28 -- 1977 85/01/10. 21.07.34. 2ND SOUTHERN TIMBER SUPPLY STUDY RUN       86/04/21. 13.21.45.   PAGE 4 REACTT
                FINAL REPORT        DUMP   2        LP ITERATIONS    2        TOTAL RP ITERATIONS   11
                 ACCURACY     2000.000        SCALE FACTORS FLWSCL, OBJSCL, AND BIG   1000.   1000. 1000000000.
                COMMODITY  PLY

PRODUCING  REGION  SUMMARY
                     MAX.  Q.           QUANTITY          SUPPLY            IMPLICIT         PRODUCER
        IDENT.       SUPPLIED           SUPPLIED           PRICE        SUPPLY  PRICE         REVENUE
        WW          100000.0000        8685.1540        79406.2436        81042.2817      689655453.97
        WE          100000.0000         961.1330        81817.6711        83492.2817       78637663.71
        SW          100000.0000         418.7490        84200.9794        84097.7233       35259075.91
        RM          100000.0000        1254.3380        85970.7724        85872.9771      107836406.70
        SC          100000.0000        5469.4440        88980.6358        89018.5712      486674604.64
        SE          100000.0000        1883.4950        87482.4324        88304.7517      164772723.97
        CA          100000.0000            .0000            .0000             .0000              .00

        ALL                           18672.3130                                         1562835928.89

MARKET  SUMMARY
                       QUANTITY          MARKET          CONSUMER           TARIFF
        IDENT.         DEMANDED           PRICE            OUTLAY          COLLECTED
        NW             2280.9050       82522.3920       188225736.51           .00
        SW             2517.4250       89667.7233       225731768.22           .00
        RK             1075.2080       90202.9771        96986962.65           .00
        NC             4358.5290       96592.2817       421000260.85           .00
        NE             2479.0190       95554.7517       236882045.06           .00
        SO             5961.2270       94568.5712       563744719.72           .00

        ALL           18672.3130                       1732571493.02

TRADE  FLOWS  AND  OPPORTUNITY  COSTS
                                    QUANTITY      OPPORTUNITY      TRANSFER       SHIPPING            TARIFF
  SOURCE    DESTINATION              SHIPPED             COST          COST           COST              COST
    WW            NW               2280.9050         706.1484       2410.00     5496981.05               .00
    WW            SW               2098.6760        1441.4797       8820.00    18510322.32               .00
    WW            RK                   .0000        1906.7336       8890.00            .00               .00
    WW            NC               3813.7900        1636.0381      15550.00    59304434.50               .00
    WW            NE                   .0000       -2131.4918      18280.00            .00               .00
    WW            SO                491.7830        -287.6724      15450.00     7598047.35               .00
    WE            NW                   .0000       -1845.2791       2550.00            .00               .00
    WE            SW                   .0000            .0521       7850.00            .00               .00
    WE            RK                   .0000        1525.3060       6860.00            .00               .00
    WE            NC                365.6090        1674.6105      13100.00     4789477.90               .00
    WE            NE                595.5240       -1732.9194      15470.00     9212756.28               .00
    WE            SO                   .0000        -279.1000      13030.00            .00               .00
    SW            NW                   .0000       -6668.5874       4990.00            .00               .00
    SW            SW                418.7490        -103.2561       5570.00     2332431.93               .00
    SW            RK                   .0000       -2118.0022       8120.00            .00               .00
    SW            NC                   .0000       -1078.6977      13470.00            .00               .00
    SW            NE                   .0000       -4486.2277      15840.00            .00               .00
    SW            SO                   .0000       -3012.4082      13380.00            .00               .00
    RM            NW                   .0000      -10378.3804       6930.00            .00               .00
    RM            SW                   .0000       -4883.0491       8580.00            .00               .00
    RM            RK               1075.2080         -97.7952       4330.00     4655650.64               .00
    RM            NC                179.1300        -508.4907      11130.00     1993716.90               .00
    RM            NE                   .0000       -5516.0207      15100.00            .00               .00
    RM            SO                   .0000       -2852.2012      11450.00            .00               .00
    SC            NW                   .0000      -22118.2438      15660.00            .00               .00
    SC            SW                   .0000      -14852.9126      15540.00            .00               .00
    SC            RK                   .0000      -12617.6587      13840.00            .00               .00
    SC            NC                   .0000        -378.3541       7990.00            .00               .00
    SC            NE                   .0000       -4075.8841      10650.00            .00               .00
    SC            SO               5469.4440          37.9353       5550.00    30355414.20               .00
    SE            NW                   .0000      -21840.0404      16880.00            .00               .00
    SE            SW                   .0000      -14694.7091      16880.00            .00               .00
    SE            RK                   .0000      -12459.4552      15180.00            .00               .00
    SE            NC                   .0000        -140.1507       9250.00            .00               .00
    SE            NE               1883.4950         822.3193       7250.00    13655338.75               .00
    SE            SO                   .0000         646.1388       6440.00            .00               .00
    CA            NW                   .0000     -917477.6080    1000000.00            .00               .00
    CA            SW                   .0000     -910332.2767    1000000.00            .00               .00
    CA            RK                   .0000     -909797.0229    1000000.00            .00               .00
    CA            NC                   .0000     -903407.7183    1000000.00            .00               .00
    CA            NE                   .0000     -904445.2483    1000000.00            .00               .00
    CA            SO                   .0000     -905431.4288    1000000.00            .00               .00

     ALL                      18672.3130                                  157904571.82
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Run 2 (30 Percent Tariff on Shipments From Canada)

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LR      28  --  1977  85/01/10.  21.07.34.  30%  TARIFF  ON  SHIPMENTS  FROM  CANADA             86/04/21.  13.32.21.    PAGE  1  REACTT
        NUMBER  OF  SUPPLY  AND  DEMAND  REGIONS  AND  PRODUCTS,  DUMP  FLAG  AND  ACCURACY
                  7  SUPPLY  REGIONS
                  6  DEMAND  REGIONS
                  2  PRODUCTS
                  DIAGNOSTIC  OUTPUT  LEVEL    2
                  REACTIVE  PROGRAMMING  ACCURACY  =      2000.000
                  FLWSCL=                      1000.
                  OBJSCL=                     1000.
                  BIG      =            1000000000.

                    PRODUCT     1       LUM       LUMBER  SUPPLY  EQUATIONS
                                     INTERCEPT        LUM  COEFFICIENT      PLY  COEFFICIENT
     WW                             -339669.337                  56.800                  2.113
     WE                             -133615.035                 105.804                 10.044
     SW                             -470226.352                 128.308                 13.019
     RM                             -520796.508                 139.745                  9.940
     SC                             -481186.553                 124.925                  6.159
     SE                             -314040.135                 130.052                  7.308
     CA                                3877.089                   8.615                   .000
                    PRODUCT     1       LUM       LUMBER  DEMAND  EQUATIONS
                                     INTERCEPT        LUM  COEFFICIENT      PLY  COEFFICIENT
     NW                              483616.423                -124.763                   .000
     SW                              531053.577                 -55.141                   .000
     RK                              484494.069                -180.888                   .000
     NC                              488194.653                 -31.465                   .000
     NE                              448538.719                 -80.940                   .000
     SO                              493826.813                 -31.609                   .000
                    PRODUCT     1       LUM       LUMBER  TARIFF  COMPUTATION  FLAGS
                                  NW               SW               RK               NC               NE               SO
     FLAG                          0                0                0                0                0                0
                    PRODUCT     1       LUM       LUMBER  TRANSPORTATION  COSTS
                          WW          WE          SW          RM          SC          SE          CA
     NW                 4590.       5370.      10490.      14590.      29610.      31920.      10120.
     SW                16820.      16520.      11720.      18050.      29400.      31920.      19720.
     RK                16160.      14430.      17090.       9110.      26180.      28710.      18810.
     NC                29660.      27550.      28330.      23430.      15160.      17470.      27250.
     NE                34870.      32550.      33310.      31770.      20060.      13520.      31250.
     SO                29470.      27520.      28150.      24100.       9560.      10930.      30050.
                    PRODUCT     1       LUM       LUMBER  TARIFF  RATES
                          WW          WE          SW          RM          SC          SE          CA
     NW                 .0000       .0000       .0000       .0000       .0000       .0000       .3000
     SW                 .0000       .0000       .0000       .0000       .0000       .0000       .3000
     RK                 .0000       .0000       .0000       .0000       .0000       .0000       .3000
     NC                 .0000       .0000       .0000       .0000       .0000       .0000       .3000
     NE                 .0000       .0000       .0000       .0000       .0000       .0000       .3000
     SO                 .0000       .0000       .0000       .0000       .0000       .0000       .3000
                    PRODUCT     1       LUM       LUMBER  LOWER  BOUND  ON  FLOWS
                          WW          WE          SW          RM          SC          SE          CA
     NW                    0.          0.          0.          0.          0.          0.          0.
     SW                    0.          0.          0.          0.          0.          0.          0.
     RK                    0.          0.          0.          0.          0.          0.          0.
     NC                    0.          0.          0.          0.          0.          0.          0.
     NE                    0.          0.          0.          0.          0.          0.          0.
     SO                    0.          0.          0.          0.          0.          0.          0.
                    PRODUCT     1       LUM       LUMBER  UPPER  BOUND  ON  FLOWS
                          WW          WE          SW          RM          SC          SE          CA
     NW             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
     SW             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
     RK             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
     NC             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
     NE             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
     SO             .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07   .1000E+07
                    PRODUCT     1       LUM       LUMBER  SUPPLY  STARTING  VALUES
                    WW         WE          SW          RM         SC         SE          CA
                    7665.      2427.       4961.       4579.      4633.      3358.       10429.
                    PRODUCT     1       LUM       LUMBER  SUPPLY  MAXIMA
                    WW         WE          SW          RM         SC         SE          CA
                    8116.      2428.       4962.       4670.      4782.      3359.       10924.
                    PRODUCT     1       LUM       LUMBER  DEMAND  STARTING  VALUES
                    NW         SW          RK          NC         NE         SO
                    2870.      7076.       1999.       11204.     3749.      11154.
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LR      28  --  1977  85/01/10.  21.07.34.  30%  TARIFF  ON  SHIPMENTS  FROM  CANADA            86/04/21.  13.32.21.   PAGE  2  REACTT
               PRODUCT    2      PLY      PLYWOOD  SUPPLY  EQUATIONS
                                 INTERCEPT      LUM  COEFFICIENT      PLY  COEFFICIENT
    WW                          -118164.479                1.989                20.989
    WE                          -151974.472               10.705               217.915
    SW                           -58534.511               11.224               218.132
    RM                          -225886.760               11.168               208.671
    SC                          -308655.918                8.097                65.792
    SE                          -521450.482                9.608               306.337
    CA                                 .000                 .000                  .000
               PRODUCT    2      PLY      PLYWOOD  DEMAND  EQUATIONS
                                 INTERCEPT      LUM  COEFFICIENT      PLY  COEFFICIENT
    NW                           340038.847                 .000              -112.901
    SW                           231640.675                 .000               -56.396
    RK                           543402.934                 .000              -421.500
    NC                           218041.385                 .000               -27.865
    NE                           222725.452                 .000               -51.299
    SO                           271838.771                 .000               -29.737
               PRODUCT    2      PLY      TARIFF  COMPUTATION  FLAG
                           NW                SW                RK                NC                NE                SO
    FLAG                    0                 0                 0                 0                 0                 0
               PRODUCT    2      PLY      PLYWOOD  TRANSPORTATION  COSTS
                        WW           WE           SW           RM           SC           SE           CA
    NW               2410.        2550.        4990.        6930.       15660.       16880.     1000000.
    SW               8820.        7850.        5570.        8580.       15540.       16880.     1000000.
    RK               8890.        6860.        8120.        4330.       13840.       15180.     1000000.
    NC              15550.       13100.       13470.       11130.        7990.        9250.     1000000.
    NE              18280.       15470.       15840.       15100.       10650.        7250.     1000000.
    SO              15450.       13030.       13380.       11450.        5550.        6440.     1000000.
               PRODUCT    2      PLY      PLYWOOD  TARIFF  RATES
                        WW           WE           SW           RM           SC           SE           CA
    NW               .0000        .0000        .0000        .0000        .0000        .0000        .0000
    SW               .0000        .0000        .0000        .0000        .0000        .0000        .0000
    RK               .0000        .0000        .0000        .0000        .0000        .0000        .0000
    NC               .0000        .0000        .0000        .0000        .0000        .0000        .0000
    NE               .0000        .0000        .0000        .0000        .0000        .0000        .0000
    SO               .0000        .0000        .0000        .0000        .0000        .0000        .0000
               PRODUCT    2      PLY      PLYWOOD  LOWER  BOUND  ON  FLOWS
                        WW           WE           SW           RM           SC           SE           CA
    NW                  0.           0.           0.           0.           0.           0.           0.
    SW                  0.           0.           0.           0.           0.           0.           0.
    RK                  0.           0.           0.           0.           0.           0.           0.
    NC                  0.           0.           0.           0.           0.           0.           0.
    NE                  0.           0.           0.           0.           0.           0.           0.
    SO                  0.           0.           0.           0.           0.           0.           0.
               PRODUCT    2      PLY      PLYWOOD  UPPER  BOUND  ON  FLOWS
                        WW           WE           SW           RM           SC           SE           CA
    NW           .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07
    SW           .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07
    RK           .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07
    NC           .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07
    NE           .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07
    SO           .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07    .1000E+07
               PRODUCT    2      PLY      PLYWOOD  SUPPLY  STARTING  VALUES
               WW         WE           SW           RM          SC          SE           CA
              9509.      1115.         915.        1327.       5115.       1705.          0.
               PRODUCT    2      PLY      PLYWOOD  SUPPLY  MAXIMA
               WW         WE           SW           RM          SC          SE           CA
            100000.    100000.      100000.      100000.     100000.     100000.      100000.
               PRODUCT    2      PLY      PLYWOOD  DEMAND  STARTING  VALUES
               NW         SW           RK          NC          NE          SO
              2271.      2628.        1082.       4803.       2673.       6229.
```

```
LR     28 -- 1977 85/01/10. 21.07.34. 30% TARIFF ON SHIPMENTS FROM CANADA          86/04/21. 13.32.21.   PAGE 3 REACTT
             FINAL REPORT        DUMP   2        LP ITERATIONS    2        TOTAL RP ITERATIONS   11
              ACCURACY     2000.000        SCALE FACTORS FLWSCL, OBJSCL, AND BIG     1000.    1000.  1000000000.
             COMMODITY  LUM

PRODUCING  REGION  SUMMARY
                      MAX. Q.          QUANTITY          SUPPLY            IMPLICIT          PRODUCER
      IDENT.          SUPPLIED         SUPPLIED           PRICE         SUPPLY PRICE          REVENUE
      WW              8116.1880        7774.9180       120356.7405        121684.6076      935763788.51
      WE              2427.5520        2315.4940       120973.7536        121466.7193      280114000.65
      SW              4962.4840        4622.4200       128313.2099        126784.6076      593117547.93
      RM              4669.7200        4524.8890       123979.0615        124886.7193      560991491.60
      SC              4782.0320        4700.8560       139754.0446        139426.7193      656963638.92
      SE              3359.0240        3359.0240       136569.6356        135482.5803      458740683.49
      CA             10924.0000       10109.7850        90971.8669         92132.7535      919706015.65

      ALL                             37407.3860                                        4405397166.74

  MARKET  SUMMARY
                        QUANTITY          MARKET           CONSUMER           TARIFF
      IDENT.            DEMANDED           PRICE             OUTLAY          COLLECTED
      NW                2881.9550      124054.4952       357519472.84              .00
      SW                7119.0680      138504.6076       986023720.15              .00
      RK                1942.2370      133167.4790       258642804.99              .00
      NC               10853.9410      146674.3135      1591994345.39     266586933.61
      NE                3700.7000      149002.5803       551413848.99       9324871.08
      SO               10909.4850      148986.7193      1625368379.82              .00

      ALL              37407.3860                       5370962572.17

TRADE  FLOWS  AND  OPPORTUNITY  COSTS
                                   QUANTITY       OPPORTUNITY       TRANSFER       SHIPPING             TARIFF
  SOURCE     DESTINATION            SHIPPED              COST           COST           COST               COST
     WW              NW           2881.9550         -892.2453        4590.00    13228173.45                .00
     WW              SW           2496.6480         1327.8671       16820.00    41993619.36                .00
     WW              RK               .0000        -3349.2615       16160.00            .00                .00
     WW              NC               .0000        -3342.4270       29660.00            .00                .00
     WW              NE               .0000        -6224.1602       34870.00            .00                .00
     WW              SO           2396.3150         -840.0212       29470.00    70619403.05                .00
     WE              NW               .0000        -2289.2584        5370.00            .00                .00
     WE              SW               .0000         1010.8540       16520.00            .00                .00
     WE              RK               .0000        -2236.2746       14430.00            .00                .00
     WE              NC               .0000        -1849.4401       27550.00            .00                .00
     WE              NE               .0000        -4521.1733       32550.00            .00                .00
     WE              SO           2315.4940          492.9657       27520.00    63722394.88                .00
     SW              NW               .0000       -14748.7147       10490.00            .00                .00
     SW              SW           4622.4200        -1528.6023       11720.00    54174762.40                .00
     SW              RK               .0000       -12235.7309       17090.00            .00                .00
     SW              NC               .0000        -9968.8964       28330.00            .00                .00
     SW              NE               .0000       -12620.6296       33310.00            .00                .00
     SW              SO               .0000        -7476.4906       28150.00            .00                .00
     RM              NW               .0000       -14514.5663       14590.00            .00                .00
     RM              SW               .0000        -3524.4539       18050.00            .00                .00
     RM              RK           1942.2370           78.4175        9110.00    17693779.07                .00
     RM              NC           1085.8320         -734.7480       23430.00    25441043.76                .00
     RM              NE               .0000        -6746.4812       31770.00            .00                .00
     RM              SO           1496.8200          907.6578       24100.00    36073362.00                .00
     SC              NW               .0000       -45309.5493       29610.00            .00                .00
     SC              SW               .0000       -30649.4369       29400.00            .00                .00
     SC              RK               .0000       -32766.5655       26180.00            .00                .00
     SC              NC               .0000        -8239.7310       15160.00            .00                .00
     SC              NE               .0000       -10811.4642       20060.00            .00                .00
     SC              SO           4700.8560         -327.3252        9560.00    44940183.36                .00
     SE              NW               .0000       -44435.1403       31920.00            .00                .00
     SE              SW               .0000       -29985.0279       31920.00            .00                .00
     SE              RK               .0000       -32112.1565       28710.00            .00                .00
     SE              NC               .0000        -7365.3220       17470.00            .00                .00
     SE              NE           3359.0240        -1087.0552       13520.00    45414004.48                .00
     SE              SO               .0000         1487.0838       10930.00            .00                .00
     CA              NW               .0000        -4328.9318       10120.00            .00                .00
     CA              SW               .0000          521.1806       19720.00            .00                .00
     CA              RK               .0000        -3905.9480       18810.00            .00                .00
     CA              NC           9768.1090         1160.8865       27250.00   266180970.25       266586933.61
     CA              NE            341.6760         -510.8467       31250.00    10677375.00         9324871.08
     CA              SO               .0000          673.2923       30050.00            .00                .00

     ALL                         37407.3860                                   690159071.06
```

```
LR     28 -- 1977  85/01/10.  21.07.34.  30%  TARIFF  ON  SHIPMENTS  FROM  CANADA          86/04/21.  13.32.21.    PAGE  4  REACTT
                FINAL  REPORT          DUMP    2          LP  ITERATIONS     2          TOTAL  RP  ITERATIONS    11
                 ACCURACY      2000.000          SCALE  FACTORS  FLWSCL,  OBJSCL,  AND  BIG    1000.    1000.  1000000000.
                COMMODITY  PLY

PRODUCING   REGION   SUMMARY
                        MAX.  Q.           QUANTITY            SUPPLY            IMPLICIT            PRODUCER
        IDENT.          SUPPLIED           SUPPLIED             PRICE         SUPPLY  PRICE           REVENUE
        WW            100000.0000          8714.6780        80204.9623         80924.6018        698960420.12
        WE            100000.0000           955.8130        81097.4929         82839.0216         77514037.93
        SW            100000.0000           418.4350        84620.8761         84081.9887         35408336.29
        RM            100000.0000          1252.1050        85923.0357         84809.0216        107584662.64
        SC            100000.0000          5469.7510        89269.6892         88381.0948        488282971.54
        SE            100000.0000          1883.0860        87679.4626         89317.7491        165107968.48
        CA            100000.0000              .0000             .0000              .0000                 .00

        ALL                               18693.8680                                            1572858397.00

  MARKET   SUMMARY
                       QUANTITY            MARKET            CONSUMER              TARIFF
        IDENT.         DEMANDED             PRICE              OUTLAY           COLLECTED
        NW             2273.7110        83334.6018        189478800.77                 .00
        SW             2517.7040        89651.9887        225717170.67                 .00
        RK             1078.5440        88796.8538         95771313.89                 .00
        NC             4381.9730        95939.0216        420402202.50                 .00
        NE             2459.2720        96567.7491        237486361.53                 .00
        SO             5982.6640        93931.0948        561958179.34                 .00

        ALL           18693.8680                         1730814028.70

TRADE  FLOWS  AND  OPPORTUNITY  COSTS
                                     QUANTITY        OPPORTUNITY        TRANSFER        SHIPPING             TARIFF
  SOURCE      DESTINATION             SHIPPED               COST            COST            COST               COST
     WW               NW            2273.7110           719.6395         2410.00      5479643.51                .00
     WW               SW            2099.2690           627.0265         8820.00     18515552.58                .00
     WW               RK                .0000          -298.1085         8890.00             .00                .00
     WW               NC            3828.7850           184.0594        15550.00     59537606.75                .00
     WW               NE                .0000         -1917.2131        18280.00             .00                .00
     WW               SO             512.9130         -1723.8675        15450.00      7924505.85                .00
     WE               NW                .0000          -312.8911         2550.00             .00                .00
     WE               SW                .0000           704.4959         7850.00             .00                .00
     WE               RK                .0000           839.3610         6860.00             .00                .00
     WE               NC             379.6270          1741.5288        13100.00      4973113.70                .00
     WE               NE             576.1860              .2563        15470.00      8913597.42                .00
     WE               SO                .0000          -196.3981        13030.00             .00                .00
     SW               NW                .0000         -6276.2743         4990.00             .00                .00
     SW               SW             418.4350          -538.8873         5570.00      2330682.95                .00
     SW               RK                .0000         -3944.0223         8120.00             .00                .00
     SW               NC                .0000         -2151.8544        13470.00             .00                .00
     SW               NE                .0000         -3893.1270        15840.00             .00                .00
     SW               SO                .0000         -4069.7813        13380.00             .00                .00
     RM               NW                .0000         -9518.4339         6930.00             .00                .00
     RM               SW                .0000         -4851.0470         8580.00             .00                .00
     RM               RK            1078.5440         -1456.1819         4330.00      4670095.52                .00
     RM               NC             173.5610         -1114.0141        11130.00      1931733.93                .00
     RM               NE                .0000         -4455.2866        15100.00             .00                .00
     RM               SO                .0000         -3441.9409        11450.00             .00                .00
     SC               NW                .0000        -21595.0874        15660.00             .00                .00
     SC               SW                .0000        -15157.7004        15540.00             .00                .00
     SC               RK                .0000        -14312.8353        13840.00             .00                .00
     SC               NC                .0000         -1320.6675         7990.00             .00                .00
     SC               NE                .0000         -3351.9400        10650.00             .00                .00
     SC               SO            5469.7510          -888.5944         5550.00     30357118.05                .00
     SE               NW                .0000        -21224.8608        16880.00             .00                .00
     SE               SW                .0000        -14907.4738        16880.00             .00                .00
     SE               RK                .0000        -14062.6088        15180.00             .00                .00
     SE               NC                .0000          -990.4409         9250.00             .00                .00
     SE               NE            1883.0860          1638.2865         7250.00     13652373.50                .00
     SE               SO                .0000          -188.3678         6440.00             .00                .00
     CA               NW                .0000       -916665.3982      1000000.00             .00                .00
     CA               SW                .0000       -910348.0113      1000000.00             .00                .00
     CA               RK                .0000       -911203.1462      1000000.00             .00                .00
     CA               NC                .0000       -904060.9784      1000000.00             .00                .00
     CA               NE                .0000       -903432.2509      1000000.00             .00                .00
     CA               SO                .0000       -906068.9052      1000000.00             .00                .00

        ALL                        18693.8680                                        158286023.76
```

Appendix 6: Subroutine REACT

A complete listing of all subroutines in REACTT is over 2,000 lines; rather than append the entire program, we include here only subroutine REACT. This subroutine displays the detailed reactive programming computations outlined in equations (14-20). Users interested in modifying REACTT to incorporate different or mixed functional forms (for example) can examine this subroutine to get an idea of how they might proceed. A full listing of REACTT is available from the authors.

```
      SUBROUTINE REACT
C
      PARAMETER (MAXREG=20, MAXPRO=5)
      COMMON / PARAM / NSUP, NDEM, NPROD, NPAGE, NLIN, LINMAX,
     2         DUMP, RUNERR, EPS, MAXIT
      INTEGER DUMP, RUNERR
C
      COMMON / ALPHA / TITLE, RDATE, RTIME, REGSUP(MAXREG),
     2         REGDEM(MAXREG),  PROD(MAXPRO)
      CHARACTER *80 TITLE
      CHARACTER *10 RDATE, RTIME
      CHARACTER *2 REGSUP, REGDEM
      CHARACTER *3 PROD
C
      COMMON / RPCOM / ACCR,SUPPLY(MAXPRO+1,MAXREG, MAXPRO),
     2         DEMAND(MAXPRO+1,MAXREG,MAXPRO), PA(MAXREG, MAXPRO),
     3         PT(MAXREG,MAXPRO), PC(MAXREG,MAXPRO), X(MAXREG, MAXPRO),
     4         TC(MAXREG,MAXREG,MAXPRO), UUU(MAXREG,MAXREG, MAXPRO),
     5         LLL(MAXREG,MAXREG,MAXPRO), Q(MAXREG,MAXREG, MAXPRO),
     6         C(MAXREG,MAXPRO), P(MAXREG,MAXPRO), FLWSCL, OBJSCL, BIG,
     7         TARIFF(MAXREG,MAXREG,MAXPRO),  TFLAG(MAXREG)
      REAL LLL
      INTEGER TFLAG, BIG
C
      COMMON / REACTP / R(MAXREG,MAXPRO), S(MAXREG,MAXPRO),
     1         PREV(MAXREG), IFAS(MAXREG,MAXPRO), IX(MAXREG, MAXPRO),
     2         NOLD, NRPIT, NLPIT, JX(MAXREG,MAXPRO), ISP 9MAXREG,MAXPRO)
               REAL ISP
      INTEGER PRINTS, FINIS, SKIP
      CHARACTER *130 DESC, DTWO
C— — — — — — — — — — — — — — — — — — — — — — — — — — — — — —
C  THE REACTIVE PROGRAMMING ALGORITHM WAS FIRST DESCRIBED BY
C  TRAMEL AND SEALE (1959), AND DESCRIBED IN MORE DETAIL BY TRAMEL
C  (1965). THIS CODE IS BASED ON THE 'TRAMEL / NCSU' PROG. PUBLISHED BY
C  KING AND HO (1972). J.  ARTHUR AND B. McCARL EXPANDED THE CODE TO
C  ACCOMMODATE PRODUCTS AND SUBSTITUTED 'NETFLO' FOR THE ORIGINAL
C  TRANSPORTATION PROBLEM SUBROUTINE. FURTHER REVISIONS TO THE
C  CODE WERE MADE  BY J. KINCAID AND D.  BROOKS.  LAST REV. FEB. 1986.
C— — — — — — — — — — — — — — — — — — — — — — — — — — — — — —
      NOLD=0
      PRINTS=10
      ITEST=4
      FINIS=5
C
      DO 10 I=1,MAXREG
      DO 10 J=1,MAXPRO
      IX(I,J)=0
      JX(I,J)=0
      IFAS(I,J)=0
      P(I,J)=0.0
      R(I,J)=0.0
      C(I,J)=0.0
      S(I,J)=0.0
      ISP(I,J)=0.0
   10 CONTINUE
C
      DO 25 I=1,NSUP
      DO 25 K=1,NPROD
      IX(I,K)=1
      DO 20 J=2,NPROD+1
      IF(ABS(SUPPLY(J,I,K)) .GT. EPS) GO TO 25
   20 CONTINUE
      IX(I,K)=0
   25 CONTINUE
C
      DO 27 K=1,NPROD
      DO 27 J=1,NDEM
      JX(J,K)=1
      DO 26 I=2,NPROD+1
      IF(ABS(DEMAND(I,J,K)) .GT. EPS) GO TO 27
   26 CONTINUE
      JX(J,K)=0
   27 CONTINUE
C
      DO 40 K=1,NPROD
      SUPMAX=PT(1,K)
      INDEX=1
      SUPTOT=0.0
      DEMTOT=0.0
      DO 30 I=1,NSUP
      PA(I,K)=PT(I,K)
      IF(PA(I,K) .GT. SUPMAX) THEN
              INDEX=I
              SUPMAX=PA(I,K)
              ENDIF
      SUPTOT=SUPTOT+PA(I,K)
   30 CONTINUE
      DO 35 J=1,NDEM
      DEMTOT=DEMTOT+X(J,K)
   35 CONTINUE
      DIF=DEMTOT-SUPTOT
      IF(ABS(DIF) .LT. .001) GO TO 0
      OLD=PA(INDEX,K)
      PA(INDEX,K)=OLD+DIF
      PT(INDEX,K)=PA(INDEX,K)
      IF(DUMP .GE. 1) WRITE(2,6010) K,PROD(K),INDEX,REGSUP(INDEX),
     2        OLD, DIF, PA(INDEX,K)
 6010 FORMAT(/' *** WARNING IN REACT'/' FOR PRODUCT',I2,1X,A3,
     2        ' REGION ',I2,1X,A2/' ALLOCATION ',F12.3,'CHANGED BY ',
     3        F12.3,' TO ',F12.3)
   40 CONTINUE
C
      NRPIT=0
      NLPIT=0
      DO 49 K=1,NPROD
```

```
             DO 48 I=1,NSUP
             IFAS(I,K)=0
      48     S(I,K)=PA(I,K)
             DO 49 J=1,NDEM
      49     R(J,K)=X(J,K)
C                      BEGIN BY SOLVING NETWORK ALLOCATION PROBLEM
             GO TO 400
      80     IF(MOD(NRPIT,ITEST).EQ.0)  THEN
                   DO 81 K=1,NPROD
                   DO 81 I=1,NSUP
                   IFAS(I,K)=0
      81     CONTINUE
                   ENDIF
C                                  START REACTIVE PROGRAMMING ALGORITHM
             NRPIT=NRPIT+1
             FINIS=0
             DO 225 K=1,NPROD
             DO 225 I=1,NSUP
             DO 85 J=1,NDEM
             R(J,K)=0.
      85     S(J,K)=0.
             IF(PT(I,K))88,87,88
      87     IF(IX(I,K) .EQ. 0) GO TO 225
      88     CONTINUE
             IF(IFAS(I,K))225,93,225
C            CALCULATE TOTAL NET REVENUE (SUM), TOTAL SHIPMENTS (CNT) AND
C            AVERAGE NET REVENUE
      93     COST=C(I,K)
             SUM=0.0
             CNT=0.0
             DO 100 J=1,NDEM
             IF(Q(I,J,K))98,100,98
      98     IF(TFLAG(J) .GE. 1) THEN
                    SUM=SUM+(P(J,K)-(COST+TC(I,J,K))*(1.0+TARIFF(I,J,K)))*
          2             Q(I,J,K)
                                   ELSE
             SUM=SUM+(P(J,K)-COST*(1.0+TARIFF(I,J,K))-TC(I,J,K))*Q(I,J,K)
                                   ENDIF
             CNT=CNT+Q(I,J,K)
     100     CONTINUE
             PROT=CNT
             IF(CNT)102,107,102
     102     AVPN=SUM/CNT
C            AVPN REMAINS > 0 ONLY WHEN PT = PC (PRODUCTION ATCAPACITY)
             IF(AVPN)107,107,104
     104     IF(IX(I,K))                   106,105,106
     105     IF(CNT-0.99999*PT(I,K))       107,108,108
     106     IF(PC(I,K)-1.001*PT(I,K))     108,108,107
     107     AVPN=0.0
     108     SKIP=0
C                      DEFINE SLOPE OF PRICE-DEPENDENT SUPPLY EQUATION (SLOPS)
             IF(IX(I,K) .EQ. 0) THEN
     114     SLOPS=0.0
             GO TO 123
             ENDIF
     116      IF(PT(I,K) .GE. PC(I,K)) THEN
                  SLOPS=0.0
                  GO TO 123
                  ENDIF
     122     SLOPS=SUPPLY(K+1,I,K)
C            CALCULATE NET PRICE FOR SHIPMENTS TO THECURRENT MARKET (SKP)
```

```
   123   CONTINUE
         DO 160 J=1,NDEM
         IF(JX(J,K) .EQ. 0) GO TO 160
         IF(NRPIT .GE. ITEST) GO TO 125
         IF(Q(I,J,K) .EQ. 0) GO TO 159
   1251  iF(TFLAG(J) .GE. 1) THEN
                  SKP=P(J,K)-(COST+TC(I,J,K))*(1.0+TARIFF(I,J,K))-AVPN
                           ELSE
                  SKP=P(J,K)-COST*(1.0+TARIFF(I,J,K))-TC(I,J,K)-AVPN
                  ENDIF
   1251  IF(SKP) 126,159,1
C                 CHECK NET PRICE AGAINST ACCURACY (ACCR)
   126   IF(Q(I,J,K))127,159,127
   127   IF(SKP+ACCR)129,159,159
   128   IF(SKP-ACCR)159,159,129
   129   SKIP=5
         FINIS=5
C                 DEFINE SLOPE OF PRICE-DEPENDENT DEMAND EQUATION (SLOPD)
   140   SLOPD=DEMAND(K+1,J,K)
C                 COMPUTE NEW SHIPMENT S(J) USING NEWTON'S APPROXIMATION
   141   S(J,K) = Q(I,J,K)-SKP/(SLOPD-SLOPS)
C                 ADJUST PRODUCTION TOTAL (PROT)
         IF(S(J,K) .LE. 0) THEN
   145   IF(Q(I,J,K) .GE. X(J,K)) THEN
   146   S(J,K)=0.5*Q(I,J,K)
         GO TO 149
         ENDIF
   147   IF(Q(I,J,K) .GE. PROT) THEN
              S(J,K)=0.5*Q(I,J,K)
              GO TO 149
              ENDIF
   148   S(J,K)=0.0
         ENDIF
   149   PROT=PROT-Q(I,J,K)+S(J,K)
C        CALCULATE NEW COST USING SUPPLY EQUATION
         IF(IX(I,K) .EQ. 0) GO TO 160
   150            COST=SUPPLY(1,I,K)
         DO 157 IJJ=1,NPROD
         PPP=PROT
         IF(K.NE.IJJ)PPP=PT(I,IJJ)
   155   COST=COST+PPP*SUPPLY(IJJ+1,I,K)
   157   CONTINUE
         GO TO 160
   159   S(J,K)=Q(I,J,K)
   160   CONTINUE
C
         DO 161 J=1,NDEM
         IF(JX(J,K) .EQ. 0) S(J,K)=Q(I,J,K)
   161   CONTINUE
C
         IF(SKIP)167,162,167
   162   IFAS(I,K)=1
         GO TO 225
C        CALCULATE DIFFERENCE BETWEEN CURRENT SUPPLY TOTAL AND CAPACITY
   164   PROT=0.0
         DO 166 J=1,NDEM
   166   PROT=PROT+S(J,K)
   167   INDIC=0
         IF(IX(I,K))169,172,169
```

```
       169    IF(PC(I,K)-PROT)171,171,170
       170    IF(AVPN)171,200,171
       171    DIFF=PROT-PC(I,K)
              GO TO 176
       172    DIFF=PROT-PT(I,K)
              IF(DIFF)174,200,174
       174    IF(AVPN)175,175,176
       175    IF(DIFF)200,200,176
       176    TOT=0.0
C             CALCULATE CHANGE IN DEMAND QUANTITY FOR A UNIT CHANGE IN PRICE
C                     FOR EACH MARKET, R(J,K) AND TOTAL FOR ALL MARKETS, TOT
              DO 191 J=1,NDEM
              R(J,K)=0.
              IF(S(J,K) .EQ. 0) GO TO 191
       188    SLOPD=DEMAND(K+1,J,K)
       189    IF(SLOPD .EQ. 0) GO TO 191
              R(J,K)=1.0/SLOPD
              TOT=TOT+R(J,K)
       191    CONTINUE
C             RECALCULATE SHIPMENTS, S(J,K) BASED ON UNUSED CAPACITY,  DIFF
              DO 198 J=1,NDEM
              IF(S(J,K) .EQ. 0) GO TO 198
       194    IF(TOT .EQ. 0.0) GO TO 195
              S(J,K)=S(J,K)-(R(J,K)/TOT)*DIFF
       195    IF(S(J,K) .GT. 0) GO TO 198
       196    S(J,K)=0.5*Q(I,J,K)
              INDIC=5
       198    CONTINUE
C             CALCULATE NEW MARKET TOTAL, X(J,K) GIVEN REVISED SHIPMENTS
       200    DO 217 J=1,NDEM
              IF(S(J,K) .EQ. Q(I,J,K)) GO TO 217
       201    X(J,K)=X(J,K)-Q(I,J,K)+S(J,K)
C                     CALCULATE NEW MARKET PRICE, P(J,K) USING DEMAND EQUATIONS
              DO 213 JK = 1,NPROD
                      IF(JX(J,JK) .EQ. 0) GO TO 213
       205            P(J,JK) = DEMAND(1,J,JK)
                      DO 211 JKK = 1,NPROD
       207                    P(J,JK) = P(J,JK) + DEMAND(JKK+1,J,JK) * X(J,JKK)
       211    CONTINUE
       213    CONTINUE
C             CALCULATE NEW SUPPLY TOTAL, PT(I) AND STORE NEW SHIPMENTS
       214    IF(IX(I,K))215,216,215
       215    PT(I,K)=PT(I,K)-Q(I,J,K)+S(J,K)
       216    Q(I,J,K)=S(J,K)
       217    CONTINUE
C                     IF S(J) HAS BEEN SET ARBITRARILY, RECOMPUTE
              IF(INDIC)164,219,164
       219    CONTINUE
C                     CALCULATE NEW COST,C(I) USING NEW SUPPLY TOTAL
C                     FOR FIXED SUPPLY REGION,C(I) REMAINS EQUAL TO INTERCEPT
       220    CONTINUE
              DO 224 JK = 1,NPROD
       212            C(I,JK) = SUPPLY(1,I,JK)
                      IF(IX(I,JK) .EQ. 0) GO TO 224
                      DO 223 JKK = 1,NPROD
       221                    C(I,JK) =C(I,JK) + SUPPLY(JKK+1,I,JK) * PT(I,JKK)
       223            CONTINUE
       224    CONTINUE
```

```
      225  CONTINUE
  C                                       INTERMEDIATE REPORT
           IF(MOD(NRPIT,PRINTS) .EQ. 0) THEN
                IF(DUMP .LT. 3) GO TO 350
                IF(FINIS .EQ. 0) GO TO 350
                CALL REPORT(FINIS)
           ENDIF
      350  CONTINUE
  C                             END RP IF MAXIMUM ITERATIONS HAVE BEEN REACHED
           IF(NRPIT .EQ. MAXIT) THEN
                     FINIS=0
                     IF(DUMP .GT. 1) WRITE(2,6007) NRPIT
      6007           FORMAT(‘ * * * MAXIMUM RP ITERATIONS REACHED * * *’,
          2                    ‘ * * * RP ITERATIONS = ‘,I6,’ * * *’)
                     ENDIF
  C                                       CONTINUE RP IF FINIS NOT EQUAL 0
           IF(FINIS .NE. 0) GO TO 80
  C                  START NETWORK ALLOCATION SUBROUTINE
      400  NLPIT=NLPIT+1
           NOLD=NOLD+NRPIT
           NRPIT=0
           DO 420 K=1,NPROD
           DO 410 J=1,NDEM
           P(J,K)=0.0
      410  CONTINUE
           DO 420I=1,NSUP
           C(I,K)=0.0
           DO 420 J=1,NDEM
           Q(I,J,K)=0.0
      420  CONTINUE
  C
           CALL SETUP
  C
           IF(RUNERR .NE. 0) THEN
                DUMP=3
                FINIS=0
                GO TO 600
                ENDIF
  C                             NETWORK ALLOCATION COMPLETED
  C        UPDATE MARKET TOTALS X(J) AND PRODUCTION ALLOCATIONS PA(I,K)
           DO 510 I=1,NSUP
           DO 510 K=1,NPROD
           IFAS(I,K)=0 327
      510  PA(I,K)=0.0
           DO 520 J=1,NDEM
           DO 520 K=1,NPROD
      520  X(J,K)=0.0
           DO 530 I=1,NSUP
           DO 530 J=1,NDEM
           DO 530 K=1,NPROD
           X(J,K)=X(J,K)+Q(I,J,K)
      530  PA(I,K)=PA(I,K)+Q(I,J,K)
           DO 550 I=1,NSUP
           IF(IX(I,K) .EQ. 0) GO TO 550
           DO 540 K=1,NPROD
      540  PT(I,K)=PA(I,K)
      550  CONTINUE
```

```
C     RECOMPUTE SUPPLY PRICES C(I) AND MARKET PRICES P(J)
C     FOR A FIXED DEMAND REGION P(J) IS THE QUANTITY-WEIGHTED COST
C     FOR DELIVERIES TO THAT REGION
C     FOR A FIXED SUPPLY REGION C(I) IS THE INTERCEPT AND ISP(I) IS
C     THE OPPORTUNITY COST FROM THE NETWORK ALLOCATION
          DO 590 K=1,NPROD
          DO 580 I=1,NSUP
          ISP(I,K)=C(I,K)
C                   COMPUTE COST FROM SUPPLY EQUATION
          C(I,K)=SUPPLY(1,I,K)
          DO 570 KK=1,NPROD
          C(I,K)=C(I,K)+PT(I,KK)*SUPPLY(KK+1,I,K)
    570   CONTINUE
    580   CONTINUE
C
          DO 589 J=1,NDEM
          P(J,K)=DEMAND(1,J,K)
          IF(X(J,K) .EQ. 0.0) GO TO 589
          IF(JX(J,K) .EQ. 0) THEN
C                                       FIXED DEMAND
          P(J,K)=0.0
          DO 587 I=1,NSUP
          IF(TFLAG(J) .EQ. 0)
     1           WP=(C(I,K)*(1+TARIFF(I,J,K))+TC(I,J,K))*Q(I,J,K)/X(J,K)
          IF(TFLAG(J) .NE. 0)
     1            WP=((C(I,K)+TC(I,J,K))*(1+TARIFF(I,J,K)))*Q(I,J,K)/X(J,K)
          P(J,K)=P(J,K)+WP
    587   CONTINUE
                    ELSE
      C                           COMPUTE PRICE FROM DEMAND EQUATION
          DO 588 KK=1,NPROD
          P(J,K)=P(J,K)+X(J,KK)*DEMAND(KK+1,J,K)
    588   CONTINUE
          ENDIF
    589   CONTINUE
    590   CONTINUE
    600   IF(FINIS .EQ. 0) THEN
C                                       FINAL REPORT
          IF(DUMP .GT. 0)CALL REPORT(FINIS)
          RETURN
          ENDIF
C
          IF(DUMP .LT. 3) GO TO 650
C                           INTERMEDIATE REPORT AFTER NETFLO
          IF(MOD(NRPIT,PRINTS) .EQ. 0)CALL REPORT(FINIS)
    650   CONTINUE
C
          GO TO 80
C
          END
```

Brooks, David J.; Kincaid, Jonna. 1987. REACTT: an algorithm for solving spatial equilibrium problems. Gen. Tech. Rep. PNW-GTR-204. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37 p.

The problem of determining equilibrium prices and quantities in spatially separated markets is reviewed. Algorithms that compute spatial equilibria are discussed. A computer program using the reactive programming algorithm for solving spatial equilibrium problems that involve multiple commodities is presented, along with detailed documentation. A sample data set, program output, and a partial program listing are also provided.

Keywords: Computer programs/programing, models, supply /demand (forest products).

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SIMYAR: A Cable-Yarding Simulation Model

Robert J. McGaughey and Roger H. Twito

CLEMSON UNIVERSITY
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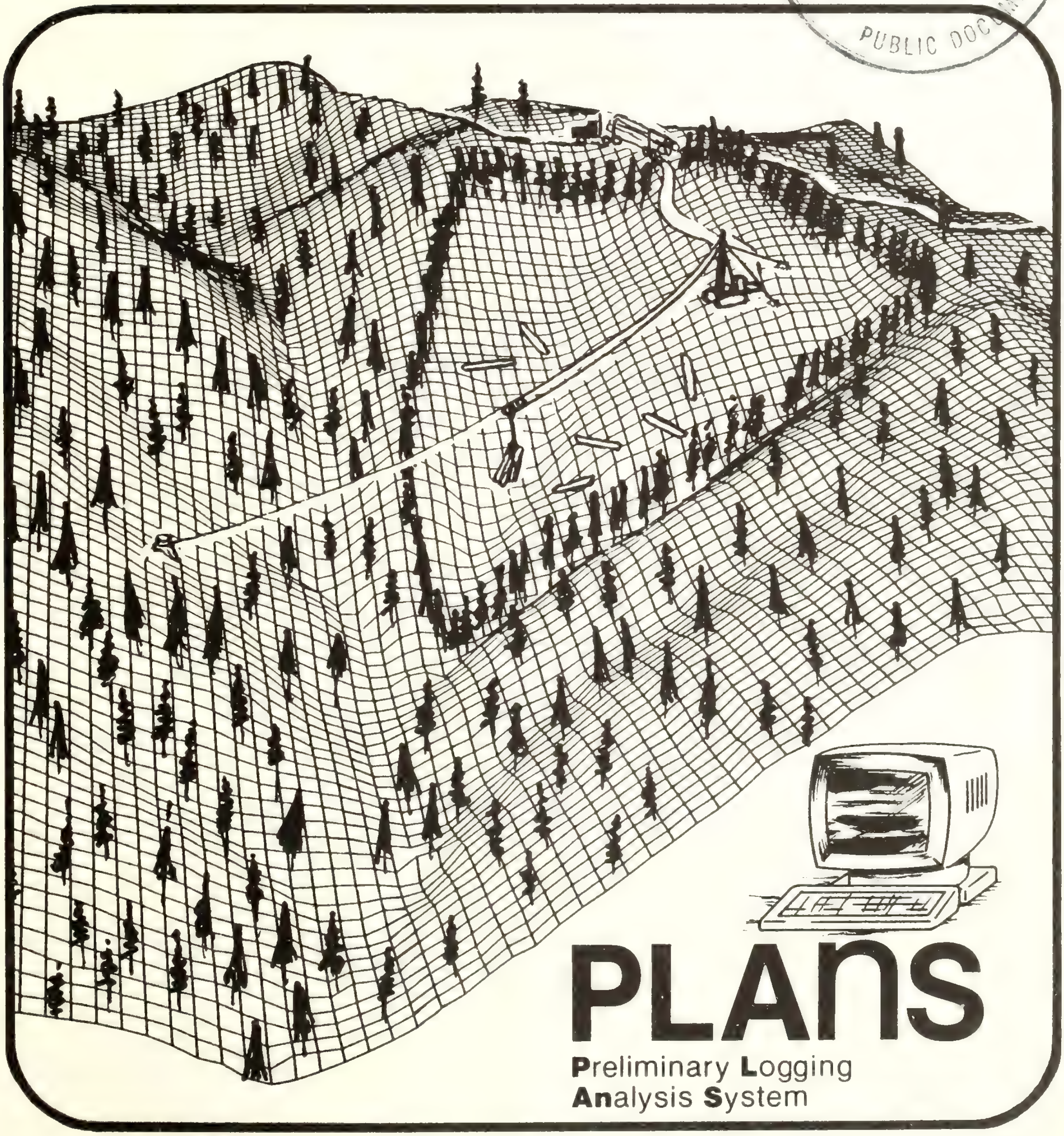

PLANS

Preliminary **L**ogging
Analysis **S**ystem

Authors

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Abstract

McGaughey, Robert J.; Twito, Roger H. 1987. SIMYAR: a cable-yarding simulation model. Gen. Tech. Rep. PNW-GTR-205. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.

A skyline-logging simulation model designed to help planners evaluate potential yarding options and alternative harvest plans is presented. The model, called SIMYAR, uses information about the timber stand, yarding equipment, and unit geometry to estimate yarding cost and productivity for a particular operation. The costs of felling, bucking, loading, and hauling are not considered. Included are a description of the input requirements for SIMYAR, descriptions of the major algorithms, suggested applications, and a discussion of limitations. A users guide is available as an appendix to this publication.

Keywords: Simulation, cable logging, yarding operations, timber harvesting, costs (logging).

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Introduction

The direct result of decisions made during timber-harvest planning is the allocation of equipment, personnel, and other resources to harvesting operations; consequently, such decisions are critical to the success or failure of a timber harvest. To help planners make better decisions, a system of computer programs called PLANS (preliminary logging analysis system) was developed. PLANS uses data from topographic maps, expressed as a digital terrain model (DTM), to show planners the projected outcomes of planning alternatives. PLANS rapidly displays the degree of success for various alternatives and, by minimizing the effort needed to redesign a landing or road, eases the fitting together of a system of harvest units and roads into a complete timber-harvest plan (Twito and others 1987). The interactive nature of PLANS supports a trial-and-error process during design of a harvest plan. Planners can quickly make modifications until the precise harvest plan meeting their objectives is created. The trial-and-error strategy for a single plan can be used to design several alternative plans for an area. Alternative plans emphasizing different harvesting objectives or logging equipment are important and give flexibility to the planning process. The best plan can be selected through a comparison.

The best alternative harvest plan is sometimes difficult to determine, but a critical factor is the cost of yarding logs from the woods to the landings. SIMYAR, the subject of this report, is a cable-yarding simulation model in PLANS that predicts yarding cost and production for cable-yarding systems. SIMYAR provides information useful for increasing the efficiency of a specific yarding operation and for comparing the yarding costs for alternative timber-harvest plans.

Simulation of Cable-Logging Systems

"A simulation model is a mathematical-logical representation of a system which can be exercised in an experimental fashion on a digital computer" (Pritsker and Pegden 1979). It is generally used when the system in question is so complex that describing it with a strict mathematical model is beyond the capabilities of the analyst. Biller and Johnson (1973) characterize timber harvesting and its relation to the environment as one such complex system.

With few exceptions, simulation analyses of timber-harvest systems have required large mainframe computers. Progress in simulation for planning purposes has been slowed by timber-harvest planning being given low priority on many central computing systems. In addition, the lack of individuals trained in both computer sciences and timber-harvest planning has led to limited interest in using mainframe simulation methods to compare harvesting alternatives.

In a study of simulation models applicable to the southeastern United States, Goulet and others (1979) found a wide range of modeling techniques used to portray logging operations. They reported no models dealing specifically with cable-logging systems. Some of the logging-system models included cable yarding as an option, but treatment of the cable-yarding process was too generalized to allow comparison of specific yarding systems and configurations. Models specifically designed to portray cable logging have been developed (LeDoux and Butler 1981, Pexton 1978), but their use has been limited to research and education.

SIMYAR uses digital terrain data describing specific harvest-unit and stand conditions to estimate the cost and productivity of yarding activities. The model, developed for a desktop computer system, uses data readily available to timber-harvest planners to provide an economic ruler for measuring the effectiveness of various timber-harvest alternatives developed with PLANS.

SIMYAR Overview

The primary objective of SIMYAR is to provide reasonable estimates of:

1. Volume per turn (turn refers to a single yarding cycle).
2. Number of logs per turn.
3. Yarding time per turn (that is, cycle time).
4. Total number of turns.
5. Total yarding cost.

Estimates of yarding-system performance can be used to compare alternative yarding systems and system configurations. Another objective for the model is to use detail commensurate with area-planning activities. The model requires input data that is both pertinent and reasonably available to logging planners. Finally, the model uses a simple question-and-answer session to obtain the data needed for each run.

SIMYAR is written for an interactive graphics work station designed around a Hewlett-Packard 9020 microcomputer.[1] The system, programmable in HP EXTENDED BASIC, also incorporates an HP 7580B drum plotter, HP 2932A printer, HP 7908 16.5 Mbyte disc drive, and a Calcomp 36- by 48-inch digitizer.

SIMYAR presents three major routines (fig. 1) designed to:

1. Accept time-study information.
2. Accept stand descriptions.
3. Simulate yarding activities.

Time-study information consists of descriptive information and regression equations derived from specific time studies. The regression equations are used during simulation activities to predict the time to complete each yarding cycle. Descriptive information provides users with details needed to judge how applicable the time study is to their conditions. Time-study data are entered interactively and stored for later retrieval, editing, and use.

Stand descriptors include location of the stand, species present, distribution of d.b.h. (diameter at breast height) classes, and the total tree height for each diameter class. The model uses stand data to generate a stand of trees for simulated felling, bucking, and yarding. Like the time-study information, stand descriptions are entered interactively and are accessed during simulations.

When using SIMYAR, users follow the process outlined in figure 2.

---

[1] The use of trade names, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

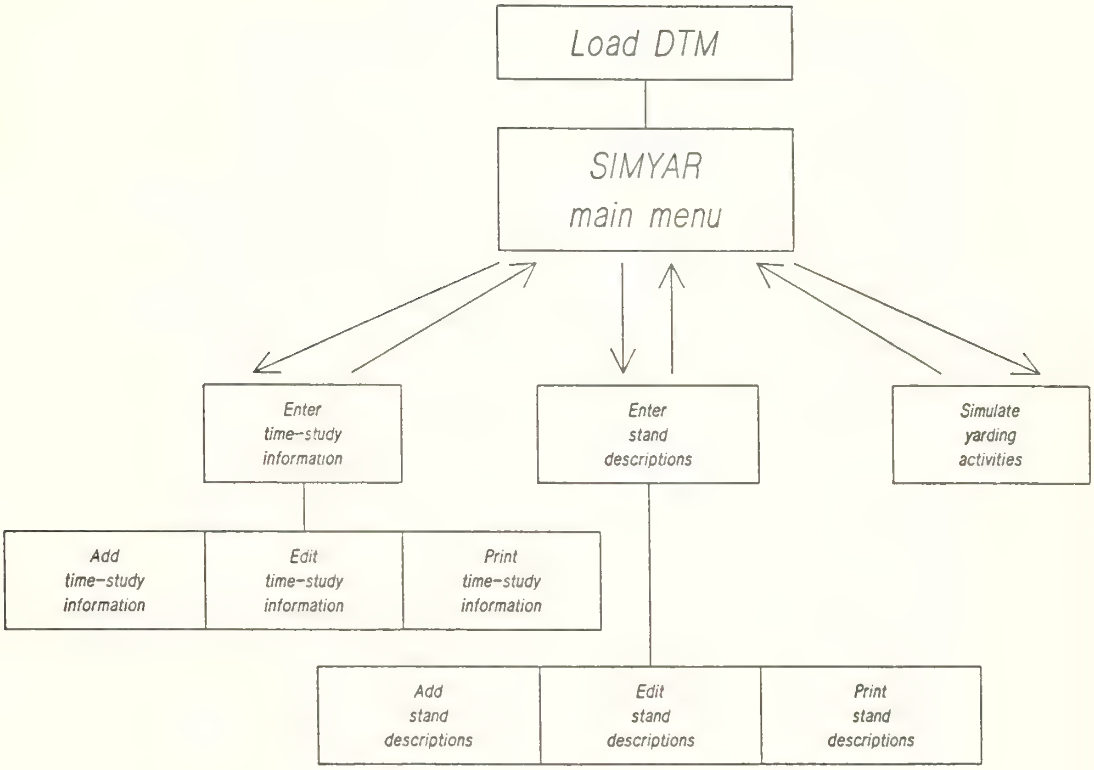

Load DTM
SIMYAR main menu
Enter time-study information
Enter stand descriptions
Simulate yarding activities
Add time-study information
Edit time-study information
Print time-study information
Add stand descriptions
Edit stand descriptions
Print stand descriptions

Figure 1—Options available on the main menu of SIMYAR.

Suggested Applications of SIMYAR

Cost and productivity output from SIMYAR is an estimate of actual behavior based on a mathematical-statistical model that has rational characteristics. Decisions based on results from SIMYAR simulation studies should be carefully examined. SIMYAR is designed to compare harvest-planning alternatives on economic and operational bases. Yet planners are advised to review skeptically any SIMYAR results before incorporating them into decision-making strategies.

SIMYAR has several applications for timber-harvest planning. Using its simulation techniques, planners can analyze proposed harvest plans and ask "what-if" questions to investigate specific alternatives. The applications include:

1. Matching equipment size and capability to stand characteristics.
2. Estimating yarding cost.
3. Investigating operational characteristics.

Matching Equipment to Stand Characteristics

The selection of yarding equipment and subsequent layout of that equipment are influenced by the design payload perceived as needed for the planning area. Although the actual payload depends on tree size and spacing, log bucking required, number of chokers, choker lengths, and the choker setters, the design payload is generally selected by using various rules of thumb or simply past experience with similar conditions. Because timber-harvest plans permitting excessive payloads (that is, physically unattainable payloads) can result in severe increases in cost, predicting the actual payload for the area and selecting a design payload accordingly may be advantageous.

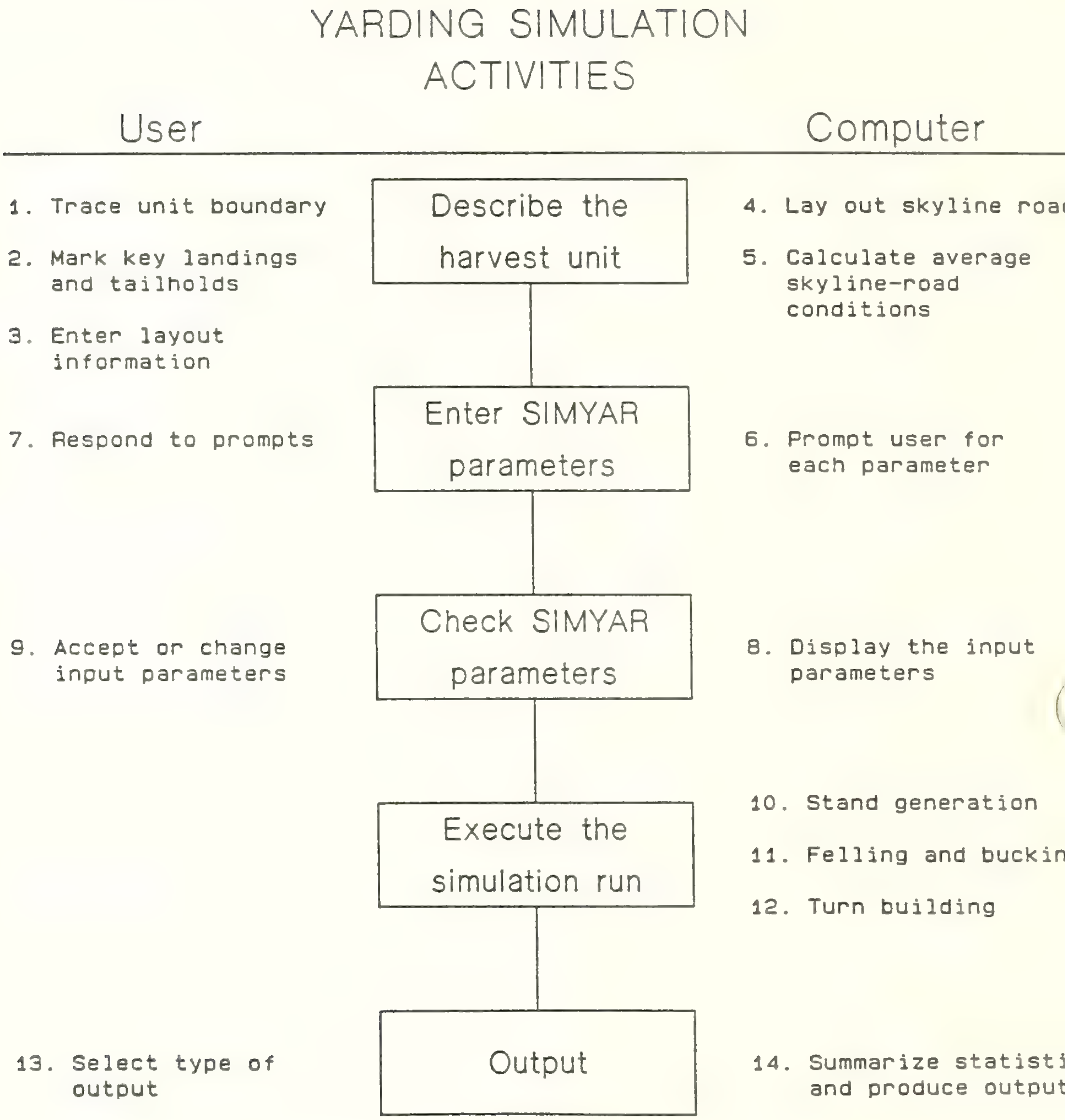

YARDING SIMULATION ACTIVITIES
User
Computer
1. Trace unit boundary
2. Mark key landings and tailholds
3. Enter layout information
Describe the harvest unit
4. Lay out skyline roa
5. Calculate average skyline-road conditions
7. Respond to prompts
Enter SIMYAR parameters
6. Prompt user for each parameter
9. Accept or change input parameters
Check SIMYAR parameters
8. Display the input parameters
Execute the simulation run
10. Stand generation
11. Felling and buckin
12. Turn building
13. Select type of output
Output
14. Summarize statisti and produce output

Figure 2—Activities in a run of SIMYAR.

Examining the relations between operating conditions and design payload is easy with SIMYAR. By varying the payload and number of chokers for representative timber stands in the planning area, users can estimate maximum and average turn weights. Then, payloads in a realistic range for the stand conditions can be used as bases for planning activities.

Estimating Yarding Cost

Valid yarding-cost estimates can be made with SIMYAR if a suitable regression equation for yarding-cycle time is used. Because cost is directly related to time, a regression equation must be used that accurately represents a yarding system operating on terrain similar to the planning area.

Yarding-cost estimates serve many useful purposes. They provide, first and foremost, an economic ruler for comparing alternative harvesting systems or harvest strategies. If the planner wishes to compare yarding patterns using the same yarding equipment, the criteria used to select a regression equation can be relaxed. Although such compromise is not desirable, it may be justified by the logic that both yarding patterns are being measured by the same economic ruler. The relative error may be tolerable, even though the absolute error is not.

A second application of yarding-cost estimates is to determine the relative value of a given timber stand. A comparison of the end-product net worth of a particular unit and the harvesting cost for that unit allows an assessment of the economic feasibility of harvesting individual units.

Investigating Operational Characteristics

The complexity and degree of interaction found in timber-harvesting systems make studying the effect of individual variables on system performance by direct observation difficult; with simulation, individual variables can be isolated and quantified. SIMYAR allows planners to experiment and see the effect a particular variable will have on performance; for example, the effect of piece size on yarding cost can be analyzed by varying the preferred and minimum log lengths and observing the resulting changes in yarding cost.

This type of "what-if" experimentation is useful as an educational tool. Planners can assess the effect of such things as skyline payload capacity and lateral yarding distance on performance. In some low-density stands, a large allowable skyline payload (15,000 pounds or greater) is not important because full payload turns are physically impossible or economically infeasible. Planners may discover that a smaller, less costly yarding system could easily perform the yarding operation at substantial cost savings. By asking these questions, planners can verify what is and is not important in skyline-system design and layout.

Input Requirements

Because SIMYAR is designed for large-area planning applications, modeling detail has been held commensurate with readily available parameters. Three major categories of data are required by SIMYAR:

1. Harvest-equipment specifications—parameters describing the yarding equipment.
2. Harvest-unit geometry—parameters describing the yarding area and the number of skyline-road changes in the harvest unit.
3. Timber-stand characteristics—parameters describing the distribution of tree diameters and heights for the stand being harvested.

Harvest-Equipment Specifications

Type of system—The type of yarding equipment being evaluated for the harvest determines the regression equation used for the yarding-cycle time. Several regression equations and their associated time-study descriptions can be entered by the user and stored for later use.

Average payload—The area-weighted average of the allowable payloads for each yarder and tailhold combination on a harvest unit can be calculated within SIMYAR when yarding to several landings with parallel skyline roads, or it can be entered directly. If the harvest unit is yarded to a single landing, the average payload (calculated by other PLANS design programs) must be entered directly. When payloads are calculated within SIMYAR, the percentage of deflection for the skyline is calculated at the limiting point on a profile. This deflection is applied at midspan to determine the payload capacity for the profile by using a rigid-link approach as described by Carson (1976). An average payload for the unit is obtained by calculating an area-weighted average of all profiles for the unit.

Number of chokers—The number of chokers used with the selected yarding system is a constraint on the maximum number of logs yarded in a single turn. The model does not hook more than one log to a choker.

Choker length—The choker length, or total length in feet of the chokers being used for the yarding operation, is another possible constraint on the maximum number of logs yarded in a single turn. Logs too widely scattered cannot be hooked simultaneously. The model uses only 80 percent of the choker length (horizontal distance) when building turns to allow for the impossibility of stretching chokers tautly from a log to the actual hook point. An additional reduction in choker length corresponding to the diameter of each log is made as the log is hooked.

Machine rate—Machine rate is defined as the hourly cost of owning and operating the yarding system. Machine rate includes both fixed and variable costs and can be calculated using a cost guide (for example, Mifflin and Lysons 1978). This parameter directly affects the validity of yarding-cost estimates, so care should be taken to ensure its accuracy.

Skyline-road change time—Depending on the regression equations used for cycle-time estimates, the skyline-road change time—the time required to move the yarding system between skyline roads—may or may not be needed. If the regression analysis for the yarding system being evaluated considers skyline-road changes as a separate yarding activity (that is, not included in the regression equation), the change time should be entered. If the regression equation includes skyline-road changes, enter 0.0 for the skyline-road change time.

Moving cost—The cost of transporting equipment to and from the sale area and the initial placement of the yarder are the moving costs. A reasonable assumption is that the moving costs will be about the same for several systems on the same unit, so the cost can be set at a constant value with little effect on the results.

Preferred log length—The preferred log length is the length in feet of the longest log to be cut during bucking. Load-size restrictions determine the longest log that can be hauled and thus the longest log that should be cut. Industrial requirements may also dictate a maximum desirable log length. The bucking algorithm increases or decreases log lengths by 2-foot intervals. The model adds a trim allowance of 6 inches per 16 feet of log length.

Minimum log length—The minimum log length is the length in feet of the shortest log to be cut during bucking. Minimum log length will usually be dictated by industrial requirements. The model adds a trim allowance of 6 inches per 16 feet of log length.

Harvest-Unit Geometry

With the exception of the number of choker setters, parameters describing the harvest-unit geometry are calculated from the digitized unit boundary and digital terrain information. These parameters cannot be changed without digitizing a new unit boundary.

Skyline-road shape—The skyline-road shape is the shape of the area to be yarded from one yarder and tailhold placement. More information about the skyline-road shape is in the description of the average skyline-road algorithm.

External yarding distance—The external yarding distance is the horizontal distance, in feet, measured along the skyline from the yarding spar to the most distant logs to be yarded over the cableway.

Maximum lateral yarding distance—The maximum lateral yarding distance is the distance, in feet, measured perpendicular to the mainline that logs can be yarded across.

Average chordslope—The SIMYAR program uses a value for the average chordslope that meets the needs of the simulation but is theoretically incorrect. The program uses chordslope as the slope, in percent, from the base of the tower to the base of the tailhold. This approximation disregards the possible difference in height between the tower and tailhold.

Average groundslope—Average groundslope is the average slope, in percent, of the harvest unit and is derived from the average chordslope according to the following assumptions:

External yarding distance (Feet)	*Groundslope*
< 600	Chordslope
600-1000	Chordslope * 1.25
>1000	Chordslope * 1.60

Groundslope is approximated because actual calculation of average groundslope for a large area can be misleading. Positive and negative slopes tend to cancel one another to yield an underestimate of the average groundslope. The assumed relations between chordslope and groundslope are based on the logic that as the span increases, deflection must also increase and thereby increase the difference between chordslope and groundslope.

Number of skyline-road changes on the harvest unit—The number of skyline-road changes is the number of different yarder or tailhold placements, or both, needed for the harvest.

Number of choker setters—The machine rate should reflect the number of choker setters used for a yarding operation in a particular run of SIMYAR. This parameter is used only if required by a particular regression equation.

Timber-Stand Characteristics

Wood density—Wood density is the density in pounds per cubic foot of the tree species being harvested. If several species are being harvested, calculate an average density.

Upper diameter limit—The upper diameter limit is the minimum top diameter in inches (outside bark) that stems should be bucked to. This merchantability limit is often dictated by industrial requirements.

Average felling angle—The average felling angle is the average angle, clockwise from the skyline around the tower with the tailhold at 0°, that trees will be felled at. Felling angles are determined by sampling from a uniform distribution about the average felling angle. Deviations from the average felling angle of up to 20° can occur. Herringbone felling patterns can be modeled by setting the average felling angle to 0°. The 20° variation in felling angles will result in at least 50 percent of the trees being felled in lead with the skyline. A default value of 90° is used in the model, and experimentation has shown that the felling angle has little effect on yarding cost and productivity estimates produced by SIMYAR.

Randomness factor—The value of the randomness factor for tree distribution, which ranges between zero and one, controls the spatial arrangement of trees on the harvest unit. Zero results in trees arranged in perfect rows and columns. As the randomness factor is increased to one, the orderly arrangement of trees degenerates to trees randomly placed on the harvest unit.

Stand name—The stand name is the name of the stand-data file containing tree d.b.h. classes, number of trees per acre, and total tree heights to be used for the simulation.

Run name—The run name is used to label output from the simulation. A name should be chosen that identifies the individual run.

Model Outputs

Three output summaries are available from SIMYAR: yarding summary, echo check, and stand summary. The yarding summary gives statistics on the yarding operation and a unit summary detailing yarding cost and production (fig. 3). Specifically reported are the minimum, maximum, mean, and standard deviation for turn weight, turn volume in cubic feet and board feet (Scribner), number of logs per turn, and cycle time along with frequency distributions for turn weights, number of logs per turn, and cycle times. The unit summary is the total yarded volume, number of pieces yarded, number of turns, total yarding time, total yarding cost, and cost per volume unit yarded. Additional information is provided on the yarding system and harvest area.

The echo check reports all the input parameters used for the simulation run (fig. 4). This includes parameters input by the user and parameters calculated from the DTM and the user-traced boundary.

The stand summary reports the number of trees per acre in each diameter class for the generated stand and the standing and yarded volumes on the average skyline road (fig. 5). Both standing volume and yarded volume are reported to show the effect of trees falling into or out of the average skyline road. The stand summary also includes a table of log lengths cut from each diameter class.

```
                    SPEARFISH SALE:  UNIT 3        1 May 1986

Type of system:  SKAGIT BU-90:  LIVE SKYLINE
Operating cost per hour:  $ 203.86.
Set up cost for the logging system:  $ 1000.00.
Maximum slope yarding distance:  787.53 feet.
Maximum lateral yarding distance:  42.39 feet.
Average system payload:  15000.00 pounds.
Preferred log length:  40.00 feet.
Minimum log length:  12 feet.
Small end merchantable diameter limit:  6.00 inches.
19.00 skyline-road changes are required on the harvest unit.
The average skyline road services 0.73 acres.
Skyline-road change time:  1.15 hours.
The stand contains 34230 board feet per acre (Scribner).


                              TURN STATISTICS


                           Mean       Std dev       Minimum        Maximum

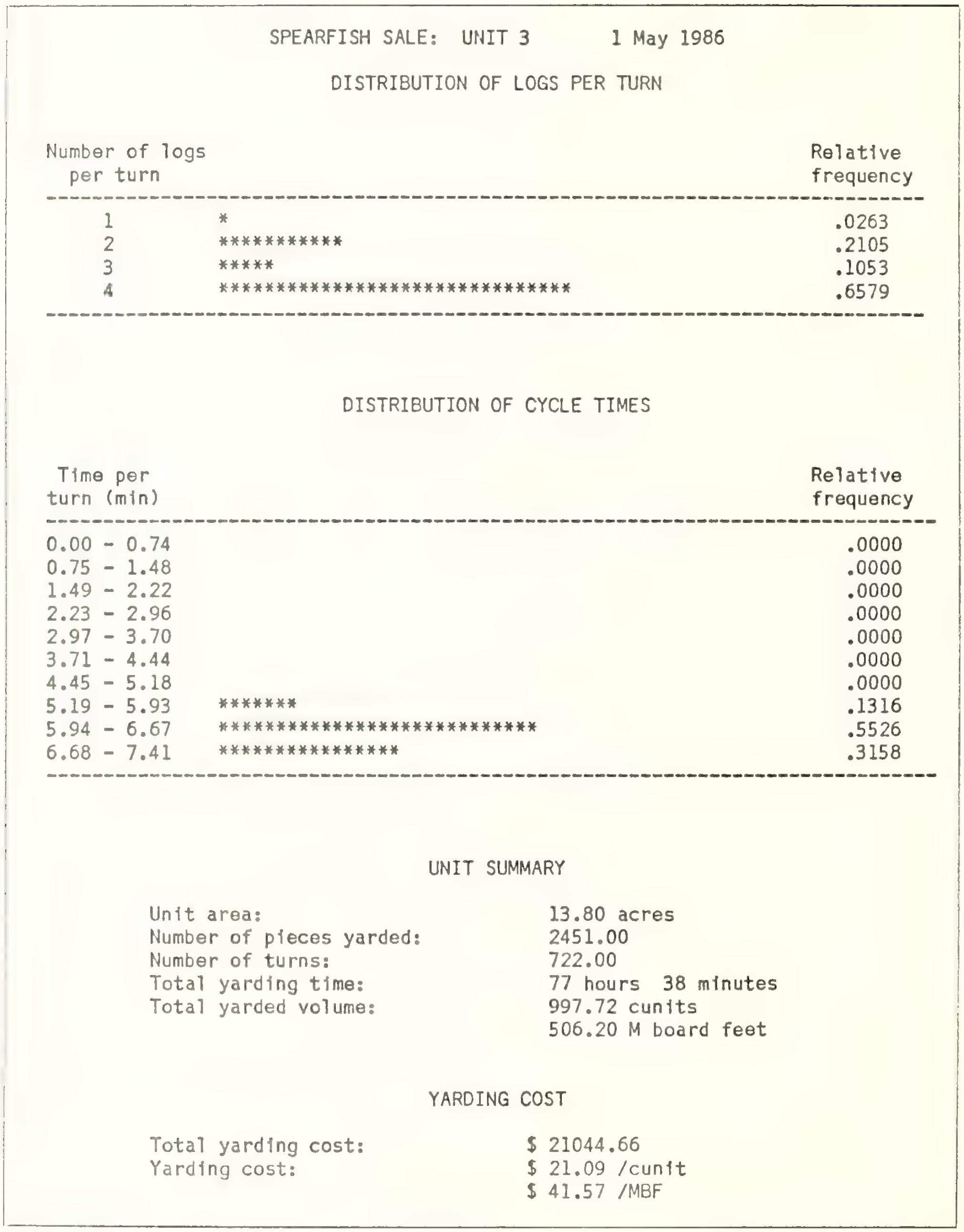
         Weight (pounds)  6909.41     3232.55       727.01        14377.02
         Volume (cu ft)    138.19       64.65        14.54          287.54
         Volume (bd ft)    701.10      403.27        31.00         1745.00
         Number of logs      3.39         .92         1.00            4.00
         Cycle time (min)    6.45         .39         5.67            7.41

       Cycle times determined using user selected regression equations.


                         DISTRIBUTION OF TURN WEIGHTS


 Weight per                                                   Relative
turn (pounds)                                                 frequency
-----------------------------------------------------------------------------
    1 - 1500   ***                                              .0526
 1501 - 3000                                                    .0000
 3001 - 4500   ********                                         .1579
 4501 - 6000   ***********                                      .2105
 6001 - 7500   ********                                         .1579
 7501 - 9000   *********                                        .1842
 9001 - 10500  *****                                            .1053
10501 - 12000  *                                                .0263
12001 - 13500  ***                                              .0526
13501 - 15000  ***                                              .0526
-----------------------------------------------------------------------------
```

Figure 3—Yarding summary from SIMYAR.



```
                   SPEARFISH SALE:  UNIT 3       1 May 1986

                      DISTRIBUTION OF LOGS PER TURN


Number of logs                                                   Relative
  per turn                                                       frequency
----------------------------------------------------------------------------
     1          *                                                  .0263
     2          ***********                                        .2105
     3          *****                                              .1053
     4          *******************************                    .6579
----------------------------------------------------------------------------



                       DISTRIBUTION OF CYCLE TIMES


 Time per                                                        Relative
turn (min)                                                       frequency
-----------------------------------------------------------------------------
0.00 - 0.74                                                         .0000
0.75 - 1.48                                                         .0000
1.49 - 2.22                                                         .0000
2.23 - 2.96                                                         .0000
2.97 - 3.70                                                         .0000
3.71 - 4.44                                                         .0000
4.45 - 5.18                                                         .0000
5.19 - 5.93     *******                                             .1316
5.94 - 6.67     ****************************                        .5526
6.68 - 7.41     ****************                                    .3158
-----------------------------------------------------------------------------



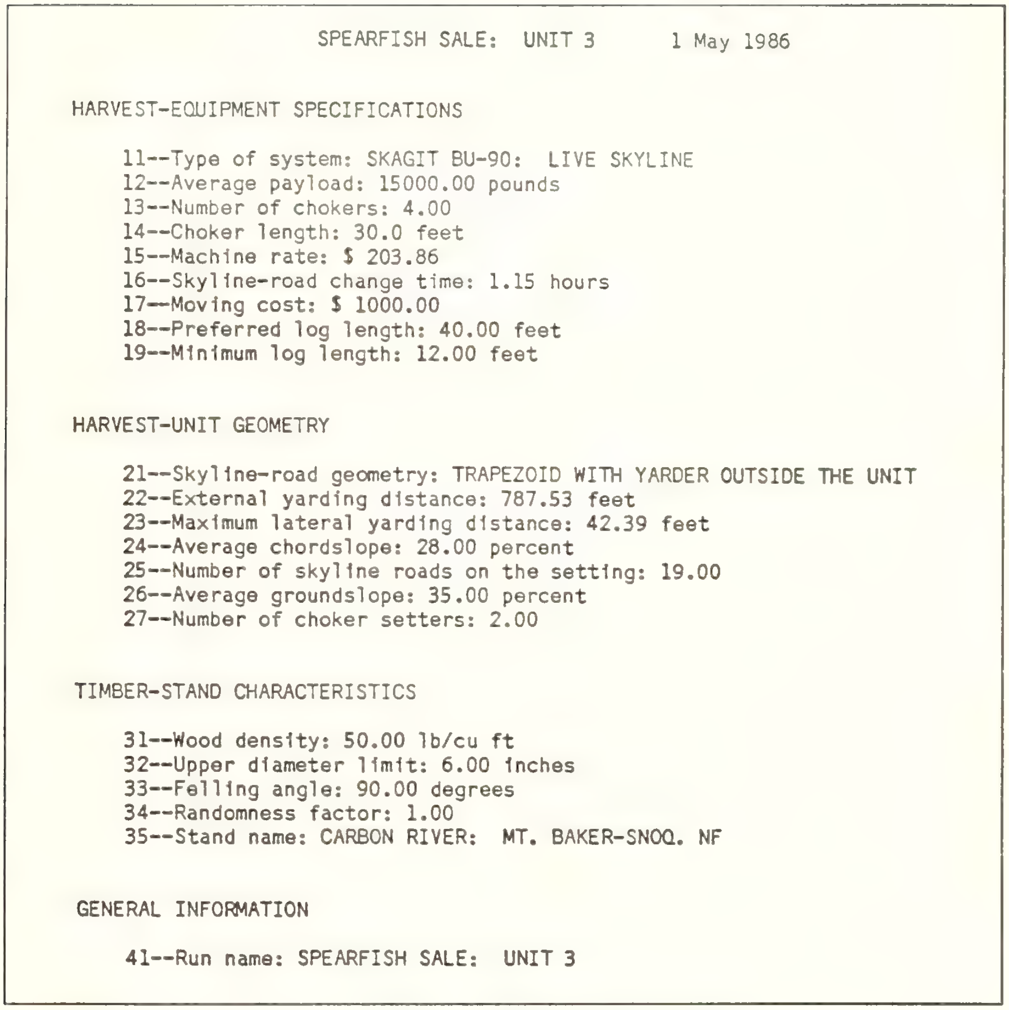
                              UNIT SUMMARY

         Unit area:                        13.80 acres
         Number of pieces yarded:          2451.00
         Number of turns:                  722.00
         Total yarding time:               77 hours  38 minutes
         Total yarded volume:              997.72 cunits
                                           506.20 M board feet


                              YARDING COST

         Total yarding cost:             $ 21044.66
         Yarding cost:                   $ 21.09 /cunit
                                         $ 41.57 /MBF
```

Figure 3 (continued)—Yarding summary from SIMYAR.



```
                        SPEARFISH SALE:  UNIT 3      1 May 1986


HARVEST-EQUIPMENT SPECIFICATIONS

    11--Type of system: SKAGIT BU-90:  LIVE SKYLINE
    12--Average payload: 15000.00 pounds
    13--Number of chokers: 4.00
    14--Choker length: 30.0 feet
    15--Machine rate: $ 203.86
    16--Skyline-road change time: 1.15 hours
    17--Moving cost: $ 1000.00
    18--Preferred log length: 40.00 feet
    19--Minimum log length: 12.00 feet


HARVEST-UNIT GEOMETRY

    21--Skyline-road geometry: TRAPEZOID WITH YARDER OUTSIDE THE UNIT
    22--External yarding distance: 787.53 feet
    23--Maximum lateral yarding distance: 42.39 feet
    24--Average chordslope: 28.00 percent
    25--Number of skyline roads on the setting: 19.00
    26--Average groundslope: 35.00 percent
    27--Number of choker setters: 2.00

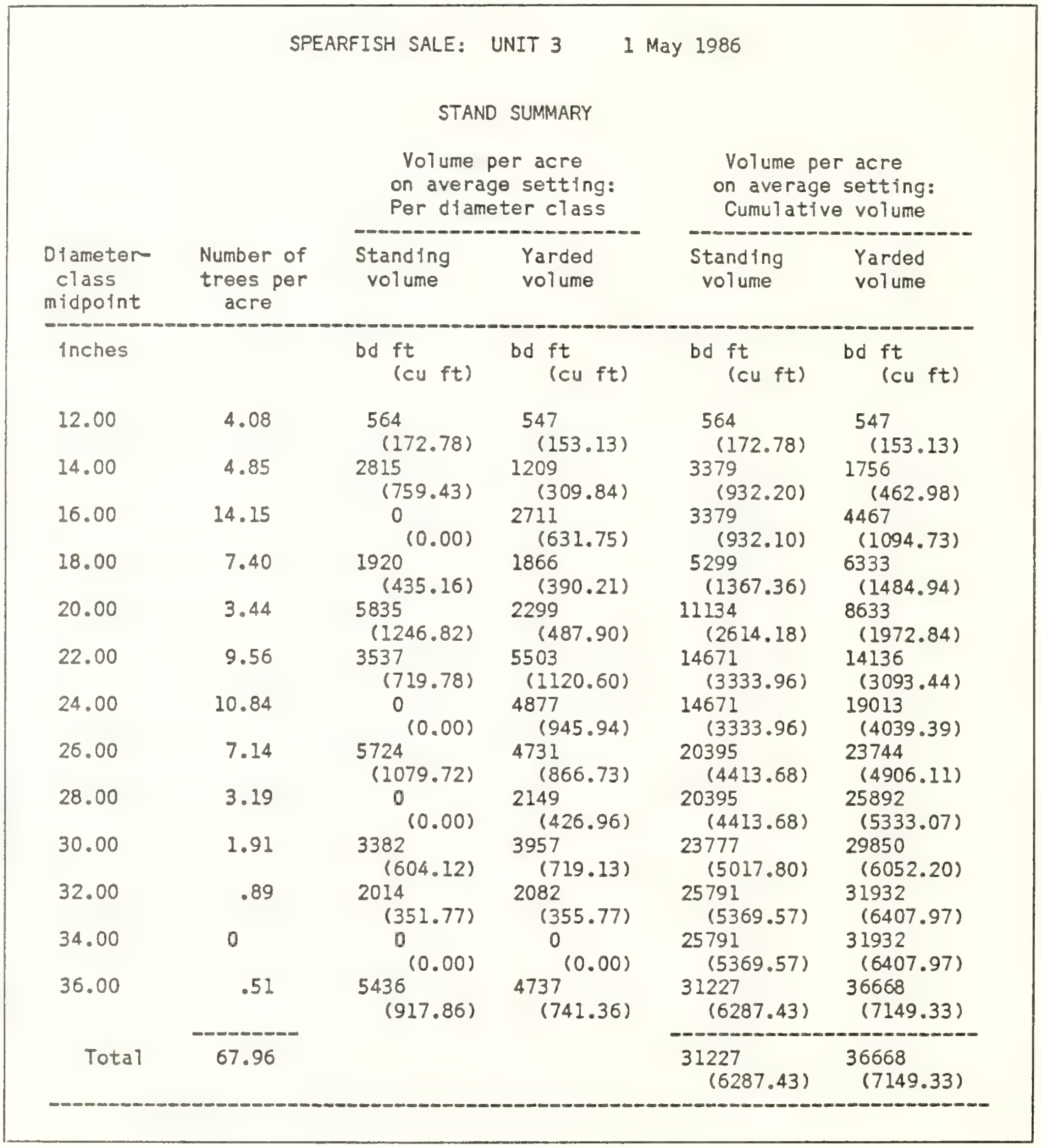

TIMBER-STAND CHARACTERISTICS

    31--Wood density: 50.00 lb/cu ft
    32--Upper diameter limit: 6.00 inches
    33--Felling angle: 90.00 degrees
    34--Randomness factor: 1.00
    35--Stand name: CARBON RIVER:  MT. BAKER-SNOQ. NF


GENERAL INFORMATION

    41--Run name: SPEARFISH SALE:  UNIT 3
```

Figure 4—Echo check from SIMYAR.



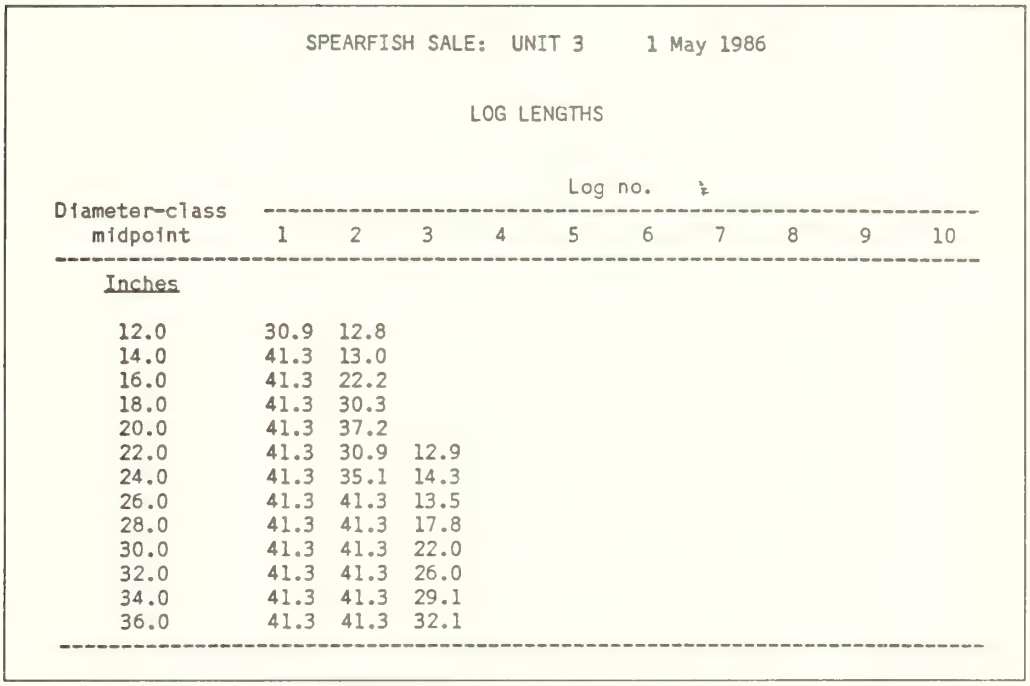
```
                   SPEARFISH SALE:  UNIT 3     1 May 1986


                                 STAND SUMMARY

                            Volume per acre           Volume per acre
                          on average setting:       on average setting:
                          Per diameter class         Cumulative volume
                         ---------------------    ----------------------
 Diameter-    Number of   Standing    Yarded       Standing    Yarded
  class       trees per    volume     volume        volume     volume
 midpoint       acre
-----------------------------------------------------------------------
  inches                  bd ft       bd ft        bd ft       bd ft
                             (cu ft)     (cu ft)      (cu ft)     (cu ft)

  12.00         4.08       564         547          564         547
                            (172.78)    (153.13)     (172.78)    (153.13)
  14.00         4.85      2815        1209         3379        1756
                            (759.43)    (309.84)     (932.20)    (462.98)
  16.00        14.15         0        2711         3379        4467
                              (0.00)    (631.75)     (932.10)   (1094.73)
  18.00         7.40      1920        1866         5299        6333
                            (435.16)    (390.21)    (1367.36)   (1484.94)
  20.00         3.44      5835        2299        11134        8633
                           (1246.82)    (487.90)    (2614.18)   (1972.84)
  22.00         9.56      3537        5503        14671       14136
                            (719.78)   (1120.60)    (3333.96)   (3093.44)
  24.00        10.84         0        4877        14671       19013
                              (0.00)    (945.94)    (3333.96)   (4039.39)
  26.00         7.14      5724        4731        20395       23744
                           (1079.72)    (866.73)    (4413.68)   (4906.11)
  28.00         3.19         0        2149        20395       25892
                              (0.00)    (426.96)    (4413.68)   (5333.07)
  30.00         1.91      3382        3957        23777       29850
                            (604.12)    (719.13)    (5017.80)   (6052.20)
  32.00          .89      2014        2082        25791       31932
                            (351.77)    (355.77)    (5369.57)   (6407.97)
  34.00        0             0           0        25791       31932
                              (0.00)      (0.00)    (5369.57)   (6407.97)
  36.00          .51      5436        4737        31227       36668
                            (917.86)    (741.36)    (6287.43)   (7149.33)
              ---------                          -----------------------
    Total      67.96                              31227       36668
                                                    (6287.43)   (7149.33)
-----------------------------------------------------------------------
```

Figure 5—Stand summary from SIMYAR.



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                    SPEARFISH SALE:  UNIT 3     1 May 1986

                                  LOG LENGTHS

                                            Log no.
 Diameter-class   ---------------------------------------------------------
    midpoint         1      2      3      4      5      6      7      8      9     10
 -----------------------------------------------------------------------------------
      Inches

       12.0        30.9   12.8
       14.0        41.3   13.0
       16.0        41.3   22.2
       18.0        41.3   30.3
       20.0        41.3   37.2
       22.0        41.3   30.9   12.9
       24.0        41.3   35.1   14.3
       26.0        41.3   41.3   13.5
       28.0        41.3   41.3   17.8
       30.0        41.3   41.3   22.0
       32.0        41.3   41.3   26.0
       34.0        41.3   41.3   29.1
       36.0        41.3   41.3   32.1
 -----------------------------------------------------------------------------------
```

Figure 5 (continued)—Stand summary from SIMYAR.

Program Algorithms

The following descriptions of the key algorithms in SIMYAR provide users with details about the general structure and operation of the program so they can make better use of the model as a planning tool. These descriptions do not provide detailed information about the internal structure and coding of the model. See McGaughey (1983) for a detailed description of the model. SIMYAR has undergone several revisions since its original version; however, the basic structure has remained the same.

Average Skyline Road

To simulate yarding activities, SIMYAR creates an average skyline road from a user-traced harvest-unit boundary and the DTM. The average provides a representative sample of the timber-harvest unit and frees the planner from a total analysis of each yarder and tailhold placement. When using SIMYAR, users trace the unit boundary and mark critical landing and tailhold locations. After the desired skyline-road spacing and average payload are entered, skyline roads are automatically placed on the unit.

Regardless of the configuration of the yarding system, a skyline road is calculated whose average yarding distance, average lateral yarding distance, and area match averages for the entire unit. Three average skyline-road shapes are possible (fig. 6):

1. A trapezoid with the yarder outside the skyline-road boundary: this shape occurs when a unit is yarded to a single landing outside the unit.
2. A trapezoid with the yarder on the skyline-road boundary: this shape occurs when a harvest unit is yarded to multiple landings; for example, parallel skyline roads.
3. A triangle with the yarder on the skyline-road boundary: this shape occurs when a harvest unit is yarded to a single landing inside the unit.

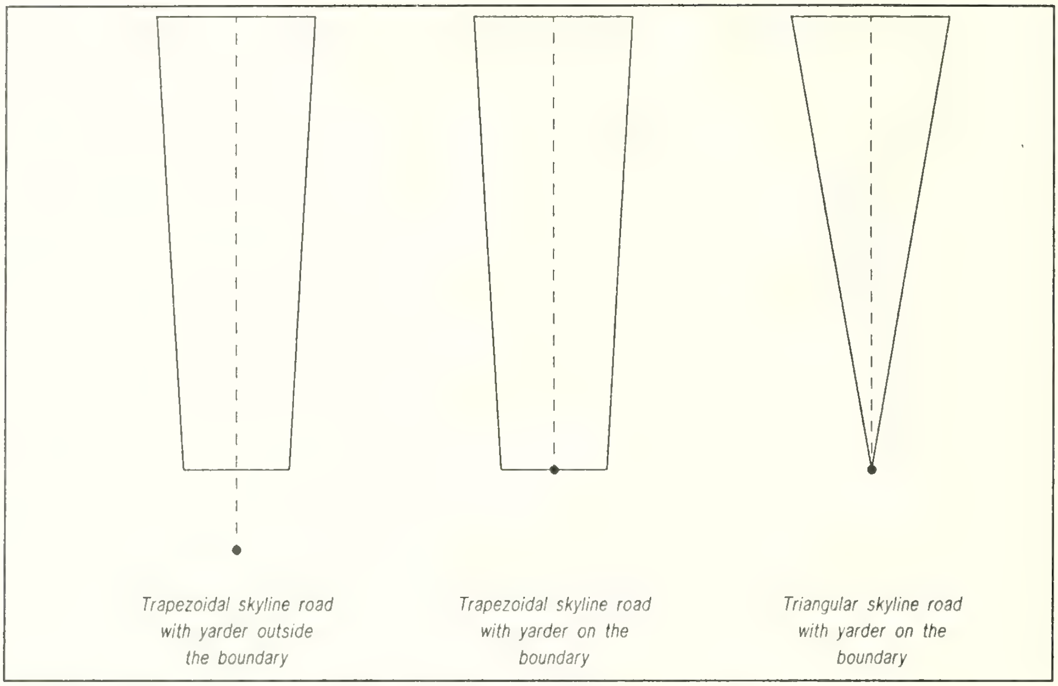

Trapezoidal skyline road with yarder outside the boundary
Trapezoidal skyline road with yarder on the boundary
Triangular skyline road with yarder on the boundary

Figure 6—Average skyline-road shapes possible in SIMYAR.

Stand Generation

The stand-generation process begins by calculating the average tree spacing, in feet, from the number of trees per acre:

$$\text{Average tree spacing} = \sqrt{\frac{43{,}560\ \text{ft}^2/\ \text{acre}}{\text{number of trees per acre}}}$$

Next, the average skyline road is overlaid by a stand grid of individual tree blocks (fig. 7). The stand grid is larger than the area delineated by the yarding boundary for the average skyline road. This allows trees outside the boundary to be felled such that some logs fall within the boundary.

To determine the actual coordinate location of each tree, one tree block is isolated within the grid. An initial coordinate corresponding to the center of the tree block is temporarily assigned to the tree. The initial coordinate will shift by a random amount within the tree block. The magnitude of the shift (that is, offset from the center of the tree block) is controlled by a variable called the randomness factor for tree distribution.

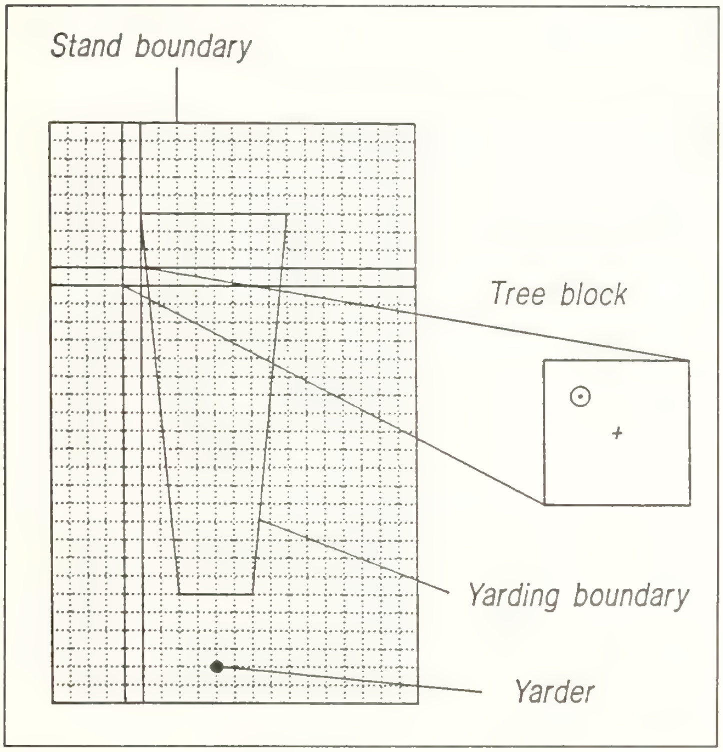


Figure 7—A rectangular grid is overlaid on the yarding area to isolate individual tree blocks.

By varying the randomness factor from zero to one, the user can influence the spatial arrangement of trees on the area. Various patterns of tree placement ranging from plantation conditions (randomness factor=0.0) to natural stands with stem clumping (randomness factor=1.0) can be modeled. Figure 8 shows three patterns possible with values for the randomness factor of 0.00, 0.50, and 1.00. Further investigation of the effect of the randomness factor on spatial distributions reveals that the row-and-column structure apparent with values of 0.00 and 0.50 disappears at values greater than 0.70. This method of tree location, similiar in concept to a log-location algorithm used by LeDoux and Butler (1981), results in a stand with the desired density and provides a framework for generating tree coordinates.

The final step in stand generation is to assign a diameter and felling angle to each tree. Diameters are assigned by sampling from actual stand inventory data (tree d.b.h., number of trees per acre, and total tree height for each diameter class) input by the user. Felling angles are determined by sampling from a uniform distribution about the average felling angle. Deviations from the average felling angle of up to 20° can occur.

As trees are felled, the location of the large end of each log in the tree is checked to see if it is within the average skyline-road boundary. Logs outside the boundary will not be considered for yarding. The large end of the log is used throughout the model to identify the log's location making it possible to track the number of logs falling into and out of the average skyline road. If locations of both the large and small ends of the log were stored and used while turns were built, the model would produce an average skyline road with too many logs. More logs would fall into the average skyline road than fall out, which would result in a distorted statistical sampling of the stand volume.

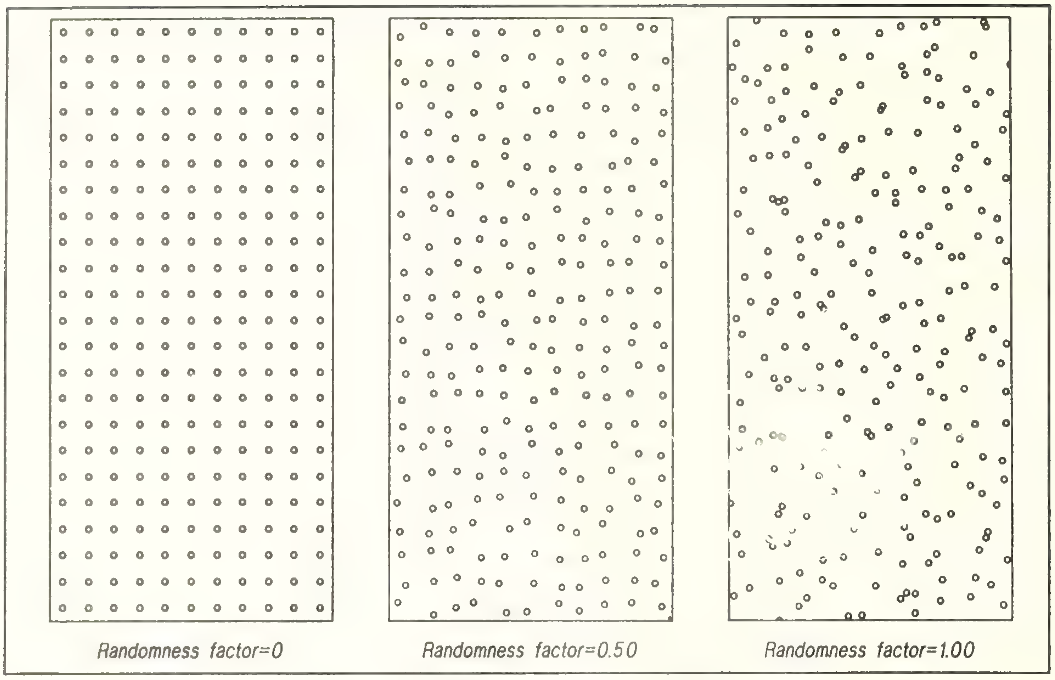


Figure 8—Spatial tree distributions on a 4.1-acre stand with 62 trees per acre.

Bucking

The bucking algorithm is designed to approximate actual bucking practices. An attempt is made to get the maximum volume from large-diameter logs, and emphasis is placed on fully using all merchantable material. One log is cut from the merchantable stem, thereby reducing its length, each time the stem passes through the algorithm. Three bucking rules are used to determine the length of each log cut from the merchantable stem:

1. Log lengths must be within a range defined by the minimum and preferred log lengths.
2. Log weights must not exceed the payload for the yarding system.
3. The length of any remaining merchantable stem after cutting a log must, whenever possible, be greater than or equal to the minimum log length. When this is impossible, a log is cut to the maximum length possible without violating the second rule.

Initial-decision rules for the algorithm are established by comparing the length of the merchantable stem with various combinations of the minimum and preferred log lengths. The bucking algorithm uses five mutually exclusive decision strategies:

1. If the remaining length of merchantable stem is greater than twice the preferred log length, then one log is cut from the stem subject to bucking rules 1 and 2.

2. If the remaining length of merchantable stem is greater than the preferred log length and also is greater than twice the minimum log length, then one log is cut from the stem subject to bucking rules 1, 2, and 3.
3. If the remaining length of merchantable stem is greater than the preferred log length but less than twice the minimum log length, then a log is cut subject to bucking rules 1, 2, and 3. In this case, some portion of the top material may be left in the field.
4. If the remaining length of merchantable stem is greater than twice the minimum log length and also less than the preferred log length, then the entire stem is checked to see if further bucking is required. If bucking is required, the log is halved and the length of the half with the largest diameter is adjusted for maximum volume subject to bucking rules 1 and 2. In this case, material might be left in the field; however, material will be left only if the payload capacity for the yarding system is low.
5. If the remaining length of merchantable stem is greater than the minimum log length, then one log is cut from the stem subject to bucking rules 1 and 2. Material might be left in the field but only if the average payload for the yarding system is low.

Where large trees are being yarded by a system with a low payload, the bucking algorithm can manufacture logs that are unyardable; that is, their length is equal to the minimum log length and their weight exceeds the payload for the yarding system. When this happens, the user is alerted and can correct the situation by changing either the payload or the minimum log length. In actual practice, these logs would usually be ripped and yarded as two or more pieces. If the user does not correct this, the resulting volume of unyarded logs will be reported on the simulation output.

Calculation of Log Volumes

The bucking algorithm characterizes the stem profile as a cone and its logs as frustums of a cone. Characterization of the tree form by any other method requires measuring tree height and diameter at many points along the stem. Such data are generally not available to timber-harvest planners. The assumption that a tree is a conoid solid allows reasonable estimates of the stem taper and volume given only d.b.h. and total tree height. Additional assumptions affecting the calculation of log volumes are that (1) bark thickness averages one-half of an inch along the entire stem, (2) logs are free of defects, and (3) board-foot volumes are calculated for 16-foot logs.

Board-foot volumes are calculated using Knouf's rule of thumb to approximate the Scribner board-foot rule (Dilworth 1971):

$$V_{bf} = \frac{D^2 - 3D}{10} * \frac{L}{2};$$

where: V_{bf} = volume in board feet,

D = small-end diameter of the log in inches, and

L = log length in feet.

Logs cut by the bucking algorithm are sectioned into 16-foot lengths to calculate board-foot volume.

Cubic-foot volumes are calculated using a standard formula for volume of frustums of a right circular cone:

$$V_{cf} = 1/4 * \pi * L \left((R + R')^2 + 1/3 \ * \ (R - R')^2 \right);$$

where V_{cf} = volume in cubic feet,

L = log length in feet,

R = radius of the large end of the log in feet,

R' = radius of the small end of the log in feet, and

π = 3.14159.

Assembling Log Loads

The turn-building algorithm assembles potential turns (the logs brought to the landing during one yarding cycle) from all logs on the average skyline road and checks each turn to see that its weight does not exceed the payload for the system. An attempt is made to carry the greatest number of logs in the turn without exceeding the payload. The algorithm uses the stand log list, a record of the location and size of each log within the average skyline road, to produce a turn file with statistics for each turn.

The turn-building algorithm begins by selecting the log closest to the yarder as the first log in a turn log list. This list will eventually contain the first log and all logs that could be combined with the first log as if forming a two-log turn. A check is made before logs are added to the turn log list to see if the difference between the weight of the first log and the maximum allowable payload is less than the weight of the lightest log in the stand log list If this condition is true, then the turn should include only the first log because no other log could be added to the turn without the weight exceeding the maximum allowable for the yarding system.

If the initial weight check of the first log indicates that more logs can be added to the turn, the algorithm attempts to build multilog turns. An effective choker length is calculated for the first log. The effective choker length is the amount of choker needed to encircle the log and secure it for yarding. This length is equal to 80 percent of the input choker length minus the large-end circumference of the log. Next, the stand log list is scanned for logs that can be combined with the first log to form a two-log turn. Two rules are used to determine if the log being checked should be added to the turn log list:

1. The straight-line distance between the large ends of the two logs must be sufficiently small so that these logs can be hooked at a common point to create a two-log turn; that is, the straight-line distance must not exceed the sum of the effective choker lengths for the two logs.
2. The sum of the log weights must be less than the maximum allowable payload for the yarding system.

When the turn log list has been completed, it is sorted by distance from the first log. The algorithm then forms and checks various combinations of logs in the turn log list until an acceptable turn is found. If needed, the logic will check all combinations of N logs (N equals the number of chokers) in the turn log list. If no satisfactory turn is found, all combinations of N-1 logs will be checked. This process will continue until a satisfactory turn is found or until N=1. When N=1, the turn will be yarded containing only the first log in the turn log list (that is, the log closest to the yarder that has not been yarded).

When a possible turn combination is checked, the algorithm determines if the logs can be hooked together by their chokers and if the combined weight of the logs exceeds the allowable payload. To check whether or not all logs can be hooked together, an average coordinate based on the location of each log in the turn is calculated, and the distance from each log to this average coordinate is compared to the effective choker length for the log. If a log that cannot be hooked is found in the combination, the combination is rejected and the next possible turn is generated and checked.

When a satisfactory turn is found, statistics describing the turn are computed and stored in the turn file. Turn statistics include total turn weight, turn volume, longitudinal yarding distance to the turn, lateral yarding distance to the turn, sum of log diameters in the turn, and the cycle time of the turn. As a turn is yarded, each of its logs is flagged in the stand log list to indicate that it has been yarded. The turn-building process continues in this fashion until all yardable logs in the stand log list have been yarded.

Regression Equations for Estimates of Cycle Time

Regression equations obtained from statistical analysis of time-study data are used to determine cycle times for yarding activities. Regression equations are of the form:

$$\text{Cycle time} = \text{constant} + ax^{i} + by^{j} + cz^{k} + \ldots$$

Any or all parameters shown below can be included in a regression equation:

Slope yarding distance in feet

Lateral yarding distance in feet

Turn volume in cubic feet

Turn volume in board feet

Number of logs in the turn

Percentage of groundslope

Percentage of chordslope

Turn weight in pounds

Number of choker setters

Cubic-foot volume per log

Board-foot volume per log

LN (slope yarding distance)

(Lateral yarding distance) * (percentage of groundslope)

Number of chokers

Slope yarding distance squared

Estimates of cycle time obtained from the equation are adjusted according to the percentage of delay time per yarding cycle observed in the time study. The following relationship is used:

$$\text{Cycle time with delay} = \text{cycle time} * \frac{100}{100 - \text{delay (\%)}}$$

Using regression equations to predict cycle time requires few inputs about the operation of the yarding system, but some disadvantages are present:

1. Regression equations are valid only for systems operating under conditions similar to those observed in the time study.
2. The sensitivity of a regression equation to various conditions not represented by the equation is difficult to determine.
3. A regression equation based on a specific yarding system and operation may be influenced by specific operating conditions rather than by the yarding system; applying the equation's projections to the yarding system may be an error.
4. Time-study procedures are not standardized, so regression equations differ widely in form and in the variables used to predict cycle times.

In SIMYAR, the equation and the operation being examined must match as closely as possible. Published information or personal communication on a particular time study should be used to verify the applicability of the regression equation. Aubuchon (1982) reviews several time studies and provides a bibliography of time-study literature. His publication is a good starting point, but planners should study the actual time-study reference if possible. Using regression equations can result in reasonable estimates of yarding cost and production despite inherent problems with the equations.

Calculating Yarding Costs

Yarding cost is based on the total time required to yard the harvest unit. As each turn on the average skyline road is yarded, its cycle time is estimated with a user-selected regression equation. Cycle times for all turns are summed to obtain an estimate of the total yarding time for the average skyline road. The total yarding cost (Tot_cost) is calculated using the following formula:

$$\text{Tot\_cost} = \text{Mach\_rate} * \frac{((\text{Cycle\_sum} * \text{N\_skyr}) + \text{Chng\_time} * (\text{N\_skyr} - 1))}{60} + \text{Set\_up} ;$$

where: Mach_rate = the hourly cost of owning and operating the yarding system;

Cycle_sum = the sum of the individual cycle times in minutes for each turn on the average skyline road, including normal operating delays;

N_skyr = the number of skyline roads on the harvest unit;

Chng_time = the time in minutes required to change skyline roads; and

Set_up = the cost of moving the yarding system to the logging site.

The yarding cost per unit of volume is obtained by dividing the total yarding cost by the total cutting-unit volume expressed in cunits (100 cubic feet) or MBF (thousand board feet).

Model Limitations

As mentioned earlier, SIMYAR was streamlined to allow use of readily available parameters, but doing this introduces several limitations. These limitations generally do not result in erroneous cost and productivity estimates; however, planners should be aware of them so cases where the estimates produced by the model have been affected can be recognized. Limitations associated with regression equations have been discussed. The remaining limitations involve the average skyline-road and turn-building algorithms.

Recall that an average skyline road is used to free the planner from a total design of each yarder and tailhold placement. When yarding to a single landing near but still within the boundary (fig. 9a), the algorithm for skyline-road layouts locates tailholds according to a specified skyline-road spacing. As a result, some corridors have a short external yarding distance (<50 feet) and a lateral yarding distance equal to one-half the skyline-road spacing (fig. 9b). In most instances, this situation does not represent reality. Material close to the landing will be yarded before normal yarding operations begin or the material will be picked up by a loader working from the landing. In addition, the average external yarding distance and area for each skyline road on the unit will be reduced as a result of the short skyline roads. To circumvent this problem, the yarding boundary can be modified as shown in figure 10, which will result in more accurate modeling of the layout because the user can define the first and last tailhold location when the landing is outside the unit.

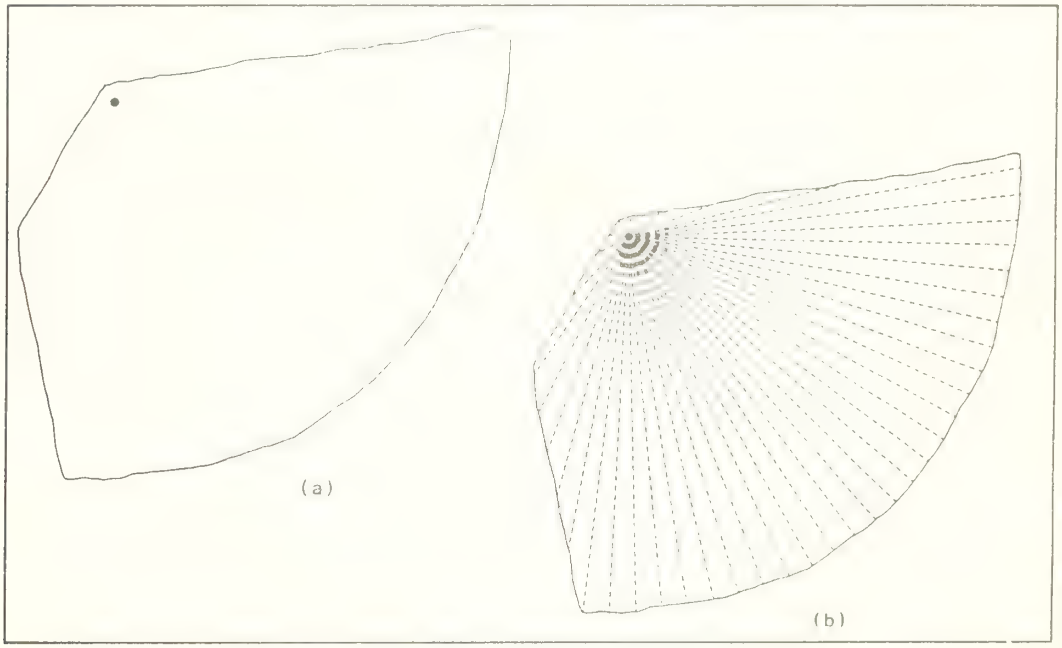


Figure 9—When an area with the landing near the unit boundary but still within the boundary (a) is yarded, the skyline-road layout algorithm produces an unrealistic yarding pattern (b).

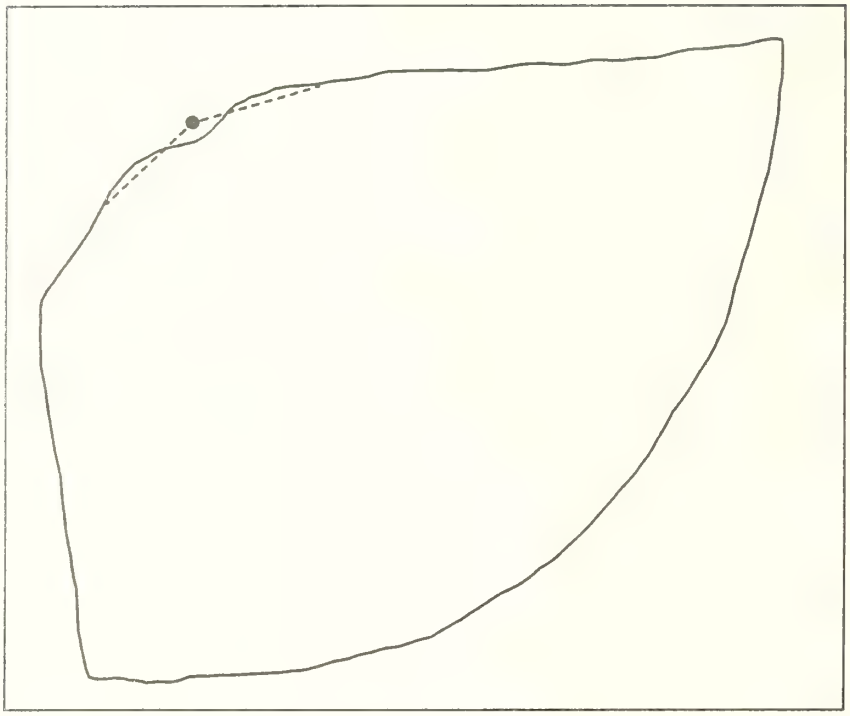


Figure 10—Modifying the unit boundary so that the landing is outside the unit allows the harvest planner to specify the first and last tailhold locations.

A second limitation is that the average skyline-road algorithm produces an abnormal skyline road for units containing a mixture of short (<50 feet) and long (>500 feet) skyline roads and a landing within the unit boundary (fig. 11). The area and average external and lateral yarding distances for the chevron-shaped skyline road (fig. 12) equal the corresponding averages for the harvest unit. Yarding activities will be modeled correctly given the parameters describing the average skyline road; however, the three-pointed, narrow, elongated boundary of the skyline road could result in incorrect statistics describing the entire unit. Comparing results from runs of chevron-shaped average skyline roads with runs from other units with standard-shaped skyline roads would clarify to what extent this peculiarity affects the specific production estimates. One way to ease this problem is to divide the unit into two units with the landing just outside both units (fig. 13), and charge the moving costs to only one unit. Cost estimates for the two-unit area can be obtained by calculating an area-weighted average. Statistics reported in the unit summary can be summed to obtain results for the two-unit area. The results will be valid for area-level analysis.

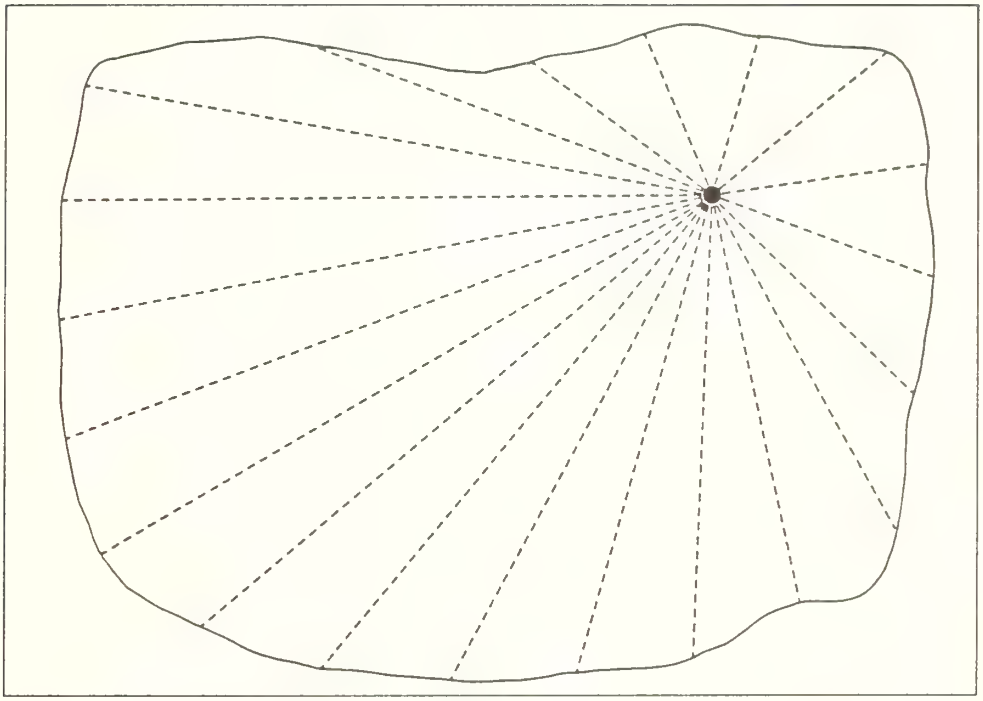


Figure 11—A unit characterized by a central landing and wide variation in external yarding distance can lead to an abnormal average skyline road.

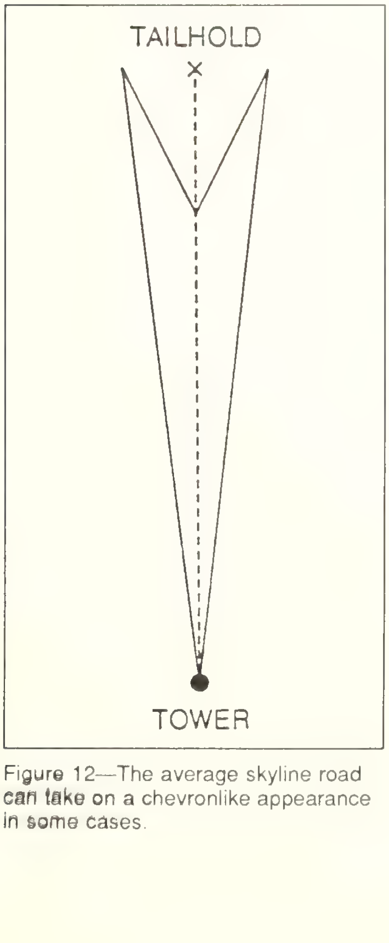


Figure 12—The average skyline road can take on a chevronlike appearance in some cases.

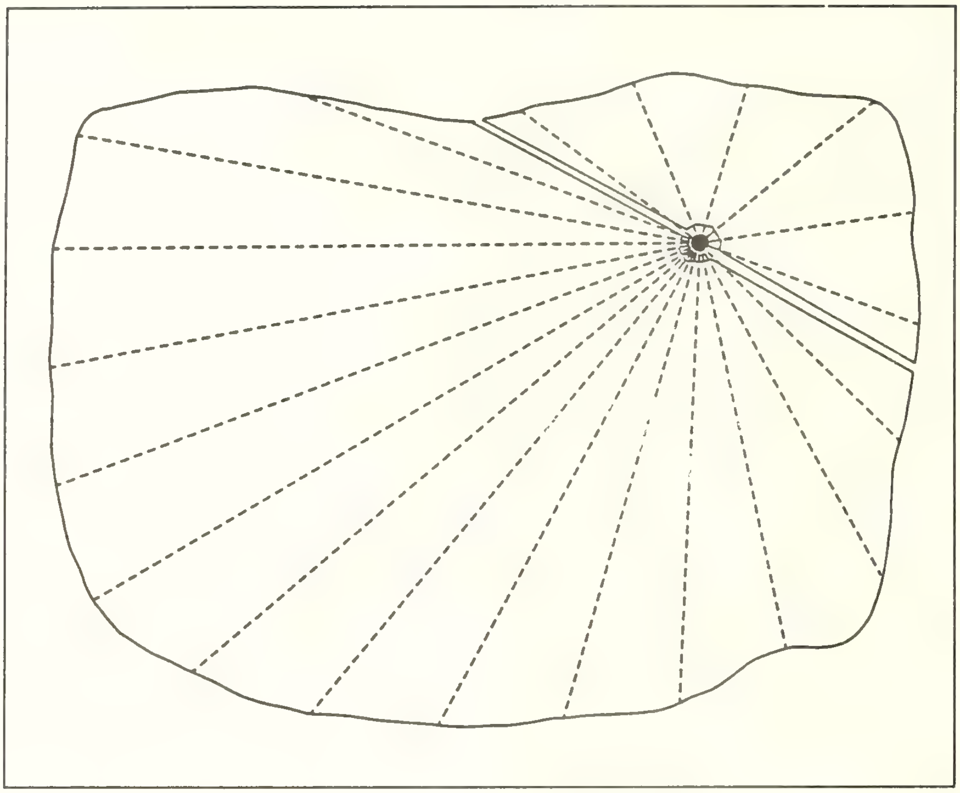
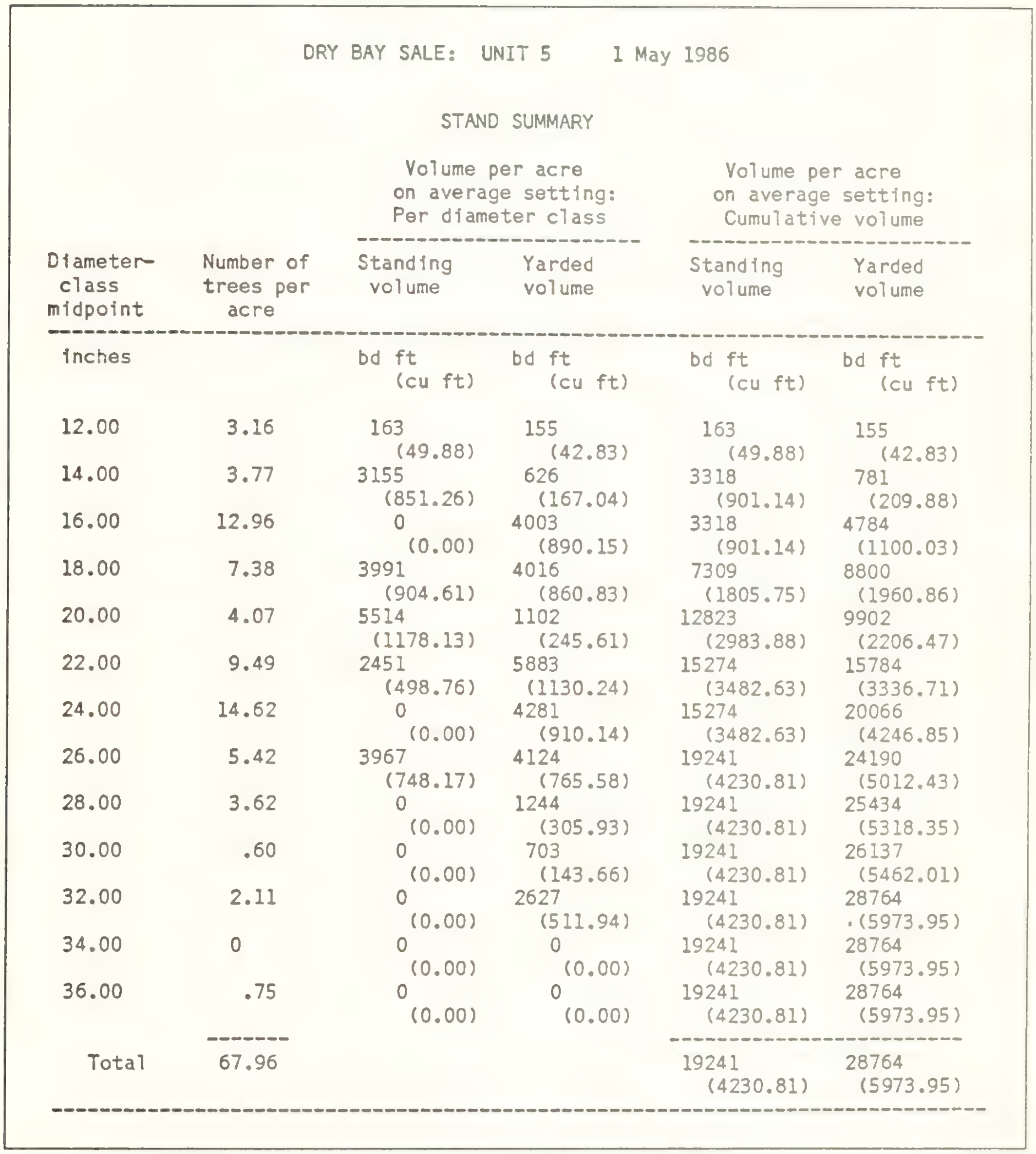


Figure 13—Dividing a unit into two separate units served by the same landing can solve problems caused by a chevron-shaped average skyline road.

The third limitation of the average skyline-road algorithm is sampling an accurate set of stand conditions on a small area. When yarding systems with limited lateral yarding capacity (<25 feet) are simulated, each yarder and tailhold combination may cover only a small area—0.5 acre or less. Experimenting with the model showed that the difference between the inventoried volume of a stand and the sampled volume of a single skyline road can be significant. Figure 14 shows a portion of the stand summary produced by modeling a 0.42-acre average skyline road. The stand being yarded contains 34,230 board feet per acre (Scribner) as inventoried. A standing volume and a yarded volume of 19,241 and 28,764 board feet per acre, respectively, are reported. (Remember that the stand created is much larger than the average skyline road to account for trees falling into the skyline road.) In this case, the calculated average skyline road should more correctly be termed a "typical skyline road." Its volume is typical of a randomly selected skyline road but does not accurately represent an average for the entire unit. A solution is to simulate yarding activities on the average skyline road several times and each time use a different random-number generator seed. This will change the sampled stand conditions and the standing and yarded volumes. Five repetitions result in estimates statistically equal to estimates produced by simulating every skyline road on a unit. Repetitive simulation is easily done and may be warranted whenever the results of a single run are suspicious.



```
                    DRY BAY SALE:  UNIT 5     1 May 1986

                                 STAND SUMMARY

                             Volume per acre          Volume per acre
                            on average setting:      on average setting:
                            Per diameter class        Cumulative volume
                           ------------------------  ------------------------
Diameter-     Number of    Standing     Yarded       Standing     Yarded
 class        trees per     volume      volume        volume      volume
midpoint        acre
-------------------------------------------------------------------------------
 inches                    bd ft        bd ft         bd ft        bd ft
                              (cu ft)      (cu ft)       (cu ft)      (cu ft)

 12.00          3.16        163         155            163          155
                              (49.88)      (42.83)       (49.88)      (42.83)
 14.00          3.77       3155         626           3318          781
                             (851.26)     (167.04)      (901.14)     (209.88)
 16.00         12.96          0         4003          3318          4784
                               (0.00)     (890.15)      (901.14)     (1100.03)
 18.00          7.38       3991         4016          7309          8800
                             (904.61)     (860.83)     (1805.75)     (1960.86)
 20.00          4.07       5514         1102          12823         9902
                            (1178.13)     (245.61)     (2983.88)     (2206.47)
 22.00          9.49       2451         5883          15274         15784
                             (498.76)    (1130.24)     (3482.63)     (3336.71)
 24.00         14.62          0         4281          15274         20066
                               (0.00)     (910.14)     (3482.63)     (4246.85)
 26.00          5.42       3967         4124          19241         24190
                             (748.17)     (765.58)     (4230.81)     (5012.43)
 28.00          3.62          0         1244          19241         25434
                               (0.00)     (305.93)     (4230.81)     (5318.35)
 30.00           .60          0          703          19241         26137
                               (0.00)     (143.66)     (4230.81)     (5462.01)
 32.00          2.11          0         2627          19241         28764
                               (0.00)     (511.94)     (4230.81)     (5973.95)
 34.00          0             0            0          19241         28764
                               (0.00)       (0.00)     (4230.81)     (5973.95)
 36.00           .75          0            0          19241         28764
                               (0.00)       (0.00)     (4230.81)     (5973.95)
              -------                                ------------------------
   Total       67.96                                  19241         28764
                                                       (4230.81)     (5973.95)
-------------------------------------------------------------------------------
```

Figure 14—A portion of a stand summary showing incorrect standing volume and yarded volume as opposed to the correct, inventoried volume of 34,230 BF/acre.

The final limitation involves the turn-building algorithm; specifically, the decision rule that determines whether or not a group of logs can be hooked as a turn. When checking a possible turn, the model calculates an average coordinate based on the coordinate location of each log in the group. The distance from each log to this average coordinate is compared to the effective choker length (80 percent of the input choker length minus the large-end circumference of the log). If a log that cannot be hooked at the average coordinate is found in the group, the turn is rejected. This approach can reject turns that, in reality, could be hooked. Figure 15 shows a situation where the turn would be rejected using the average coordinate method. In this example, log A cannot be hooked at the average coordinate (X,Y), and logs B, C, D, and E can be hooked at (X,Y). Each dashed circle represents the hook zone for a log—a circular area around the large end

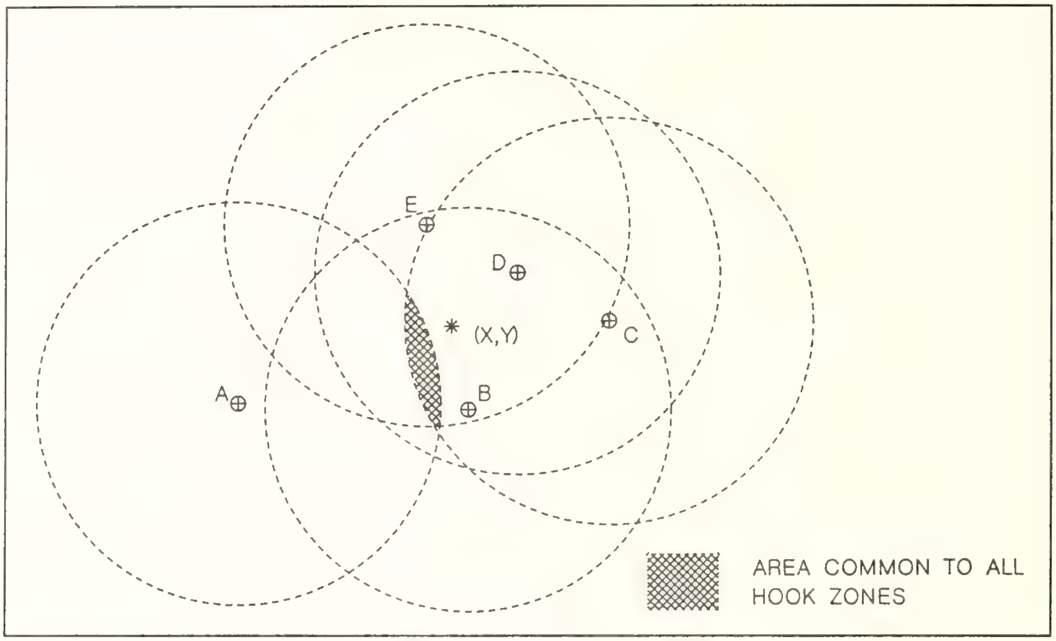


Figure 15—The average coordinate method of checking turns rejects some turns that could be hooked.

of the log with the radius equal to the effective choker length for the log. The shaded area is the intersection of the hook zones for all five logs. The turn could be hooked at any point within the shaded area even though it is rejected by the average-coordinate method. The errors caused by the average-coordinate method are conservative; that is, some turns will be rejected that could be hooked and have no significant effect on the simulation results.

Summary

Timber-harvest operations are being forced onto ground once thought of as inaccessible and unloggable and into smaller, second-growth stands to supply the demands for wood fiber. Harvesting operations run on a fine line between success and failure, and managers are finding that intensive planning is needed to ensure the success of an operation. Thorough planning can increase the ever-elusive profit margin even for those logging operations on accessible sites. The PLANS package and SIMYAR help planners to develop practical harvesting solutions and to compare the solutions economically and operationally. The package reduces the time needed to develop timber-harvest plans while it increases planning quality.

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 acre = 0.4047 hectare

1 pound = 0.4536 kilogram

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Twito, Roger H.; Reutebuch, Stephen E.; McGaughey, Robert J.; Charles N. Mann. 1987. Preliminary logging analysis system (PLANS): overview. Gen. Tech. Rep. PNW-GTR-199. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

An appendix to this report containing step-by-step operating instructions for the SIMYAR program is available on request from the Pacific Northwest Research Station. A copy of this appendix can be obtained by photocopying this page, filling in the necessary information, and sending it to:

Forestry Sciences Laboratory
Forest Engineering Systems
4043 Roosevelt Way NE
Seattle, WA 98105

This appendix includes examples of using SIMYAR to estimate yarding cost and productivity and demonstrates many of the options and manipulations that can be exercised during this process.

If you wish to receive the PLANS program set, which includes SIMYAR stored on diskettes, enclose five 5 1/4-inch double-sided, double-density, flexible, mini discs

Please send supplementary material for the SIMYAR program to:

NAME ______________________________

ADDRESS ______________________________

CITY ______________________________

STATE & ZIP CODE ______________________________

PHONE ( ) ______________________________

October 1987

McGaughey, Robert J.; Twito, Roger H. 1987. SIMYAR: a cable-yarding simulation model. Gen. Tech. Rep. PNW-GTR-205. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.

A skyline-logging simulation model designed to help planners evaluate potential yarding options and alternative harvest plans is presented. The model, called SIMYAR, uses information about the timber stand, yarding equipment, and unit geometry to estimate yarding cost and productivity for a particular operation. The costs of felling, bucking, loading, and hauling are not considered. Included are a description of the input requirements for SIMYAR, descriptions of the major algorithms, suggested applications, and a discussion of limitations. A users guide is available as an appendix to this publication.

Keywords: Simulation, cable logging, yarding operations, timber harvesting, costs (logging).

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United States
Department of
Agriculture

Forest Service

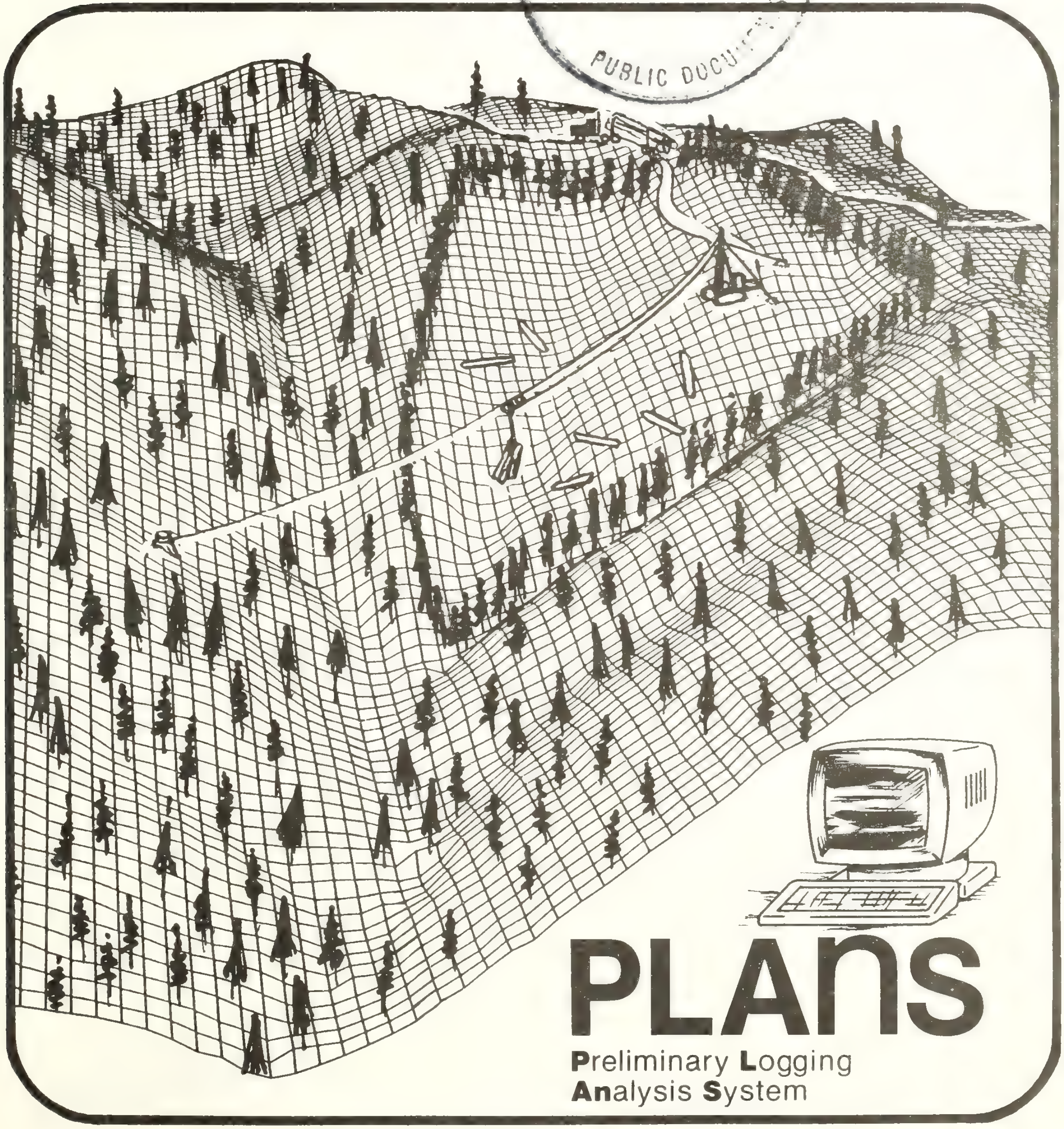
Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-206

The HIGHLEAD Program: Locating and Designing Highlead Harvest Units by Using Digital Terrain Models

Roger H. Twito, Stephen E. Reutebuch, and Robert J. McGaughey

CLEMSON UNIVERSITY
MAY 1988
PUBLIC DOCUMENTS



Authors

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Abstract

Twito, Roger H.; Reutebuch, Stephen E.; McGaughey, Robert J. 1988. The HIGHLEAD program: locating and designing highlead harvest units by using digital terrain models. Gen. Tech. Rep. PNW-GTR-206. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

PLANS, a software package for integrated timber-harvest planning, uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. HIGHLEAD, an integral program in the PLANS package, is used to design the timber-harvest units to be yarded by highlead systems. It solves for the yarding limits of direct mainline pull to the top of the tower by assuming that the angle of pull must be equal to or greater than the slope of the ground. The ground is sampled through a system of 18 uniformly spaced corridor profiles that radiate from user-selected landing locations and that are extrapolated from the digital terrain model. HIGHLEAD permits the planner to reduce the yarding coverage by shortening yarding distance on individual corridors or by deleting portions of the yarding circle. Conversely, the planner can try to extend the yarding distance on individual corridors by tightlining. The algorithm for tightlining is explained as are limitations of the analysis and interpretations on the maximum, safe log load for highlead systems. A guide giving detailed operating instructions for the program is available from the authors.

Keywords: Timber harvest planning, computer programs/programming, logging operations analysis/design, road building (forest/logging).

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3 Previous Analyses of the Highlead System

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Introduction

Highlead is the harvesting system most frequently used in the Pacific Northwest, yet little information helpful to timber-harvest planners has been published on the physical limitations of the system. The lack of analytical procedures cannot be explained by an indifference on the part of loggers to the physical layout of the highlead harvesting unit. Cable loggers appreciate that lift (deflection) is needed not only for skyline logging but also for highlead; however, some aspects of highlead yarding make it troublesome to analyze. Interactions between the logs hooked to the highlead system and the terrain make a mathematical model providing a single, correct solution for the log-moving capacity of the system impossible, especially in borderline cases; yet the predominate role of highlead yarding makes a valid process for designing highlead units important. A program providing such a process is included in the PLANS (preliminary logging analysis system package (Twito and others 1987b). The HIGHLEAD program ascertains the physical limits of boundaries for units yardable with highlead cable systems. During preliminary planning of harvest activities, a planner using this program can rapidly solve and compare alternative highlead harvesting patterns. The program includes options for extending highlead yarding distance through a tightlining technique. The capacity of the HIGHLEAD program for rapid analyses is partly the result of using stored digital terrain models (DTMs). These models, also used by other PLANS design and analysis programs, can be produced by digitizing topographic maps (Twito and others 1987a). PLANS was developed by the Forest Engineering Systems group of the Pacific Northwest Research Station, USDA Forest Service.

Background

The highlead system is both the most widely used and one of the simplest (fig. 1) cable yarding systems in the United States (Studier and Binkley 1974). Unlike skyline cable systems, highlead systems have limited lifting capacity. Logs are generally pulled along the ground and occasionally attain partial suspension while being yarded with the highlead system. Under favorable conditions (fig. 2), a limited amount of lift to overcome ground obstacles can be generated by "tightlining." Tightlining is holding tension in the haulback line while pulling the turn of logs toward the landing with the mainline. Because of the increased stress this places on the system, tightlining can cause safety problems, accelerate wear of equipment, and slow production. For these reasons, the planner should try to lay out settings that minimize the need for tightlining. When irregular terrain and difficult topography make this impossible, analyzing tightlining is desirable to ensure that its use will allow yarding without overloading the highlead system.

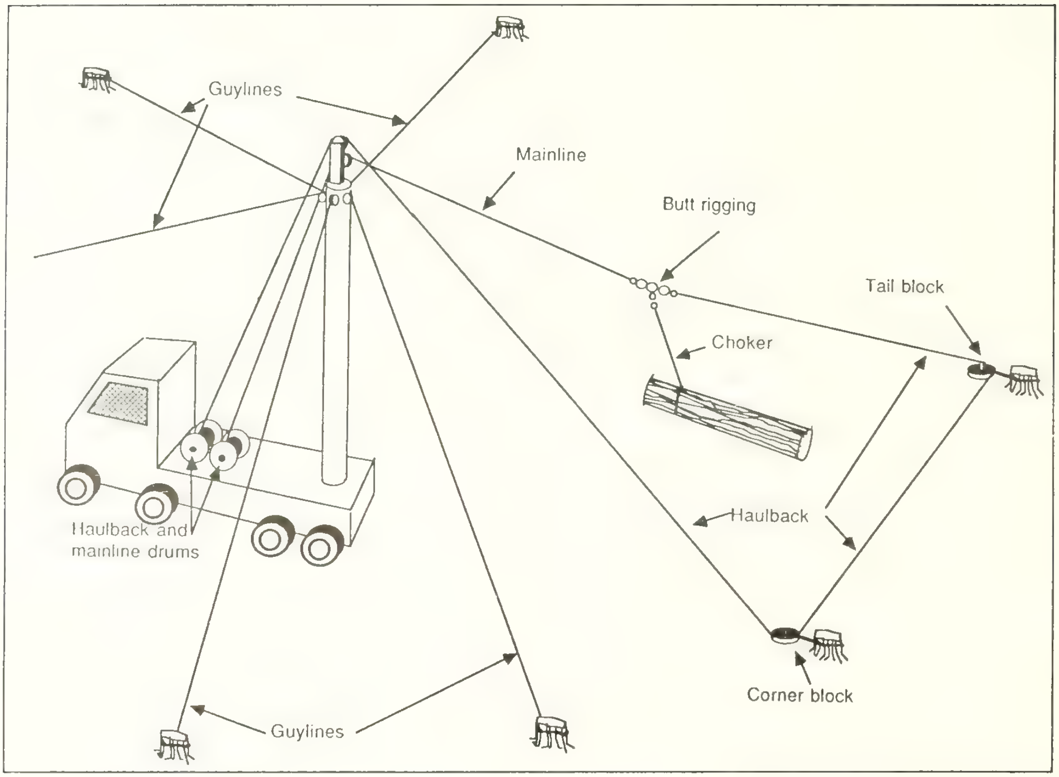


Figure 1—Highlead logging system.

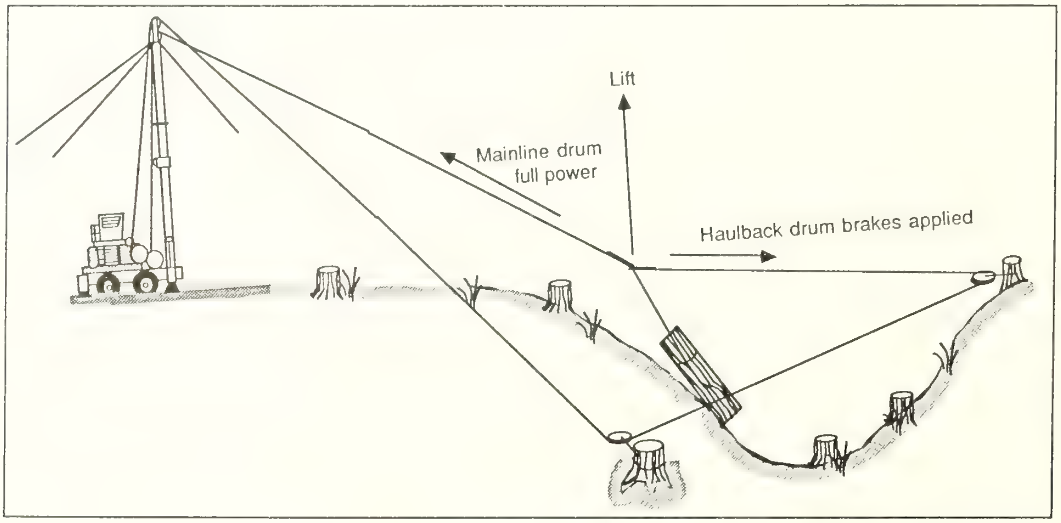


Figure 2—Tightlining logs with a highlead system.

When laying out the boundary of a highlead setting, the planner should not allow the ground to obstruct the line of sight between any point on the setting and the mainline block (Kline 1961, Pearce 1960). Although many authors have presented this general rule for planners to follow (Conway 1976, Kline 1961, Liley 1983, Pearce 1960, Studier and Binkley 1974, Wellburn 1975), few have presented analytical methods for designing highlead units.

Previous Analyses of the Highlead System

Dykstra (1976) describes a computer program for analyzing options in cable logging; it includes algorithms to determine the yarding capacity of a highlead system in terms of payload[1] and yarding distance. The program constructs ground profiles of highlead corridors by using terrain data extracted from a DTM. Dykstra's analysis of highlead payload is unique in the literature, but he does caution that the analysis is only an initial effort developed because no other analysis was available to meet his immediate research needs. He states that a more rigorous procedure should be developed for estimating highlead load capacity and that his program, as presented, should be considered experimental.

Reutebuch and Evison (1984) developed a computer program that determines maximum yarding reach and occurrences of blind lead along a highlead corridor; they did not attempt an analysis of load capacity. Their program constructs ground profiles of highlead corridors from field survey data, from data derived by digitizing single corridors drawn on a topographic map, or from a DTM.

Both of the computer programs mentioned above use a "line-of-sight" algorithm to determine occurrences of blind lead. Dykstra defines blind lead as occurring when the line of sight between the tailblock and top of the tower is obscured by the ground line of the corridor profile. Reutebuch and Evison use a more conservative definition of blind lead, however; they define it as occurring whenever the line of sight between a ground point along a highlead profile and the top of the highlead tower is obscured by the ground line. The HIGHLEAD program uses a blind lead algorithm slightly different from the "line-of-sight" approach; it is more conservative and realistic than that of either Dykstra or Reutebuch and Evison and is unique in providing an analytical basis for extending the yarding limits via tightlining.

The HIGHLEAD Program

The HIGHLEAD computer program was developed to provide an operational tool to help the planner rapidly develop and evaluate highlead setting boundaries. The program was developed on a Hewlett Packard 9020 computer in the HP BASIC 2.0 language.[2] Besides the microcomputer, a printer, a graphics plotter, and a digitizer tablet are required to execute the program.

The PLANS DTM

To use the HIGHLEAD program, the planner must first obtain a topographic map of the project area and build a DTM of the project area. The MAP program (Twito and others 1987a) is used to build the DTM. For MAP, the topographic map with the project area delineated on it is taped to the digitizer, and each contour line within the area is traced with the digitizer cursor. From these contour data, the MAP program generates a gridded DTM of the project area and stores it for use with a variety of PLANS programs, including HIGHLEAD.

---

[1] The maximum weight of logs that can be safely transported to the landing in one yarding cycle.

[2] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Preliminary Highlead Setting Design Using DTMs

In a typical run of the HIGHLEAD program, the topographic map of the project area, with the boundary of DTM coverage marked on it, is taped to the digitizer tablet, and the DTM is loaded into the computer. Next, the height of the highlead tower, the height of the tailhold, and the maximum yarding distance for the highlead system are entered. The planner then marks the location of likely highlead landings on the map. The digitizer cursor is positioned over one of the likely landings, and its position (the x-y coordinates) is sent to the computer. The program automatically extracts ground profiles for each of 18 evenly spaced yarding corridors radiating from the landing (fig. 3).

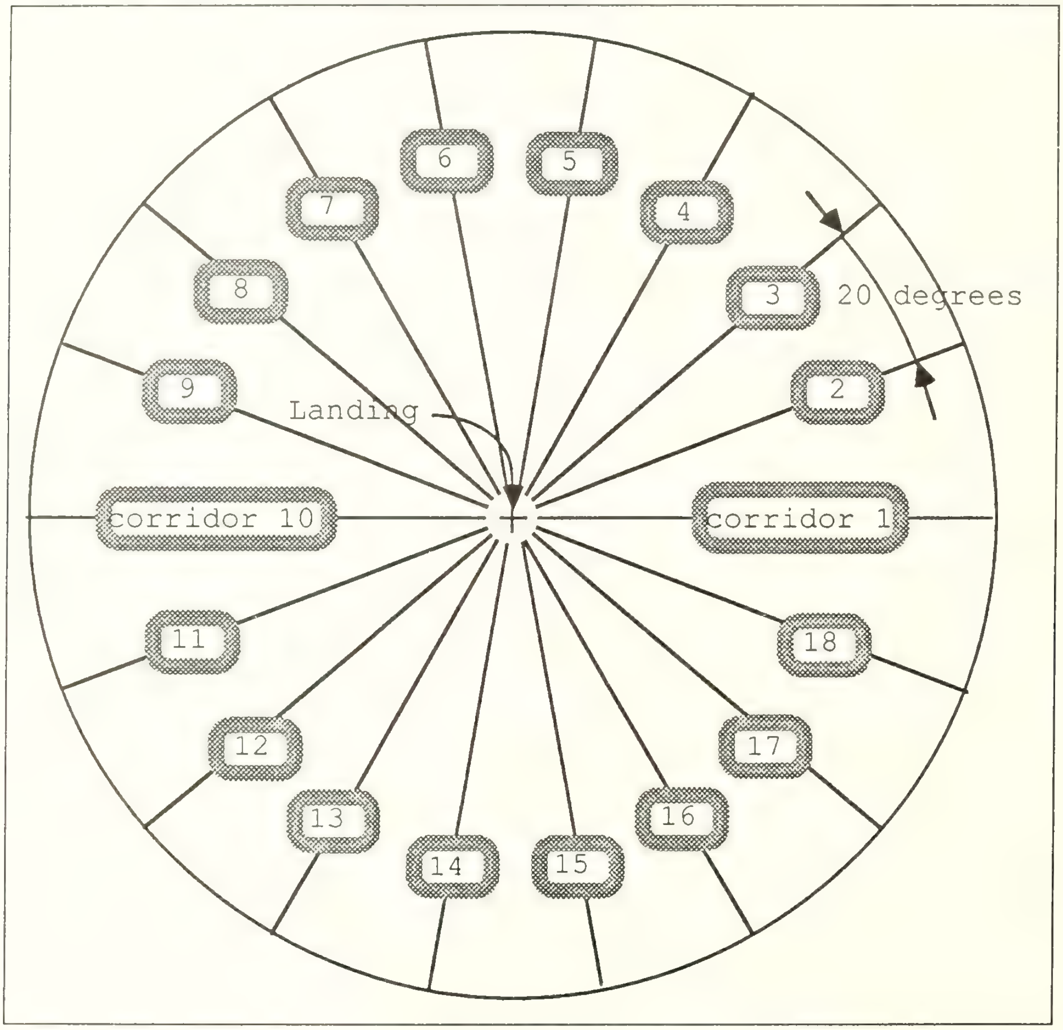
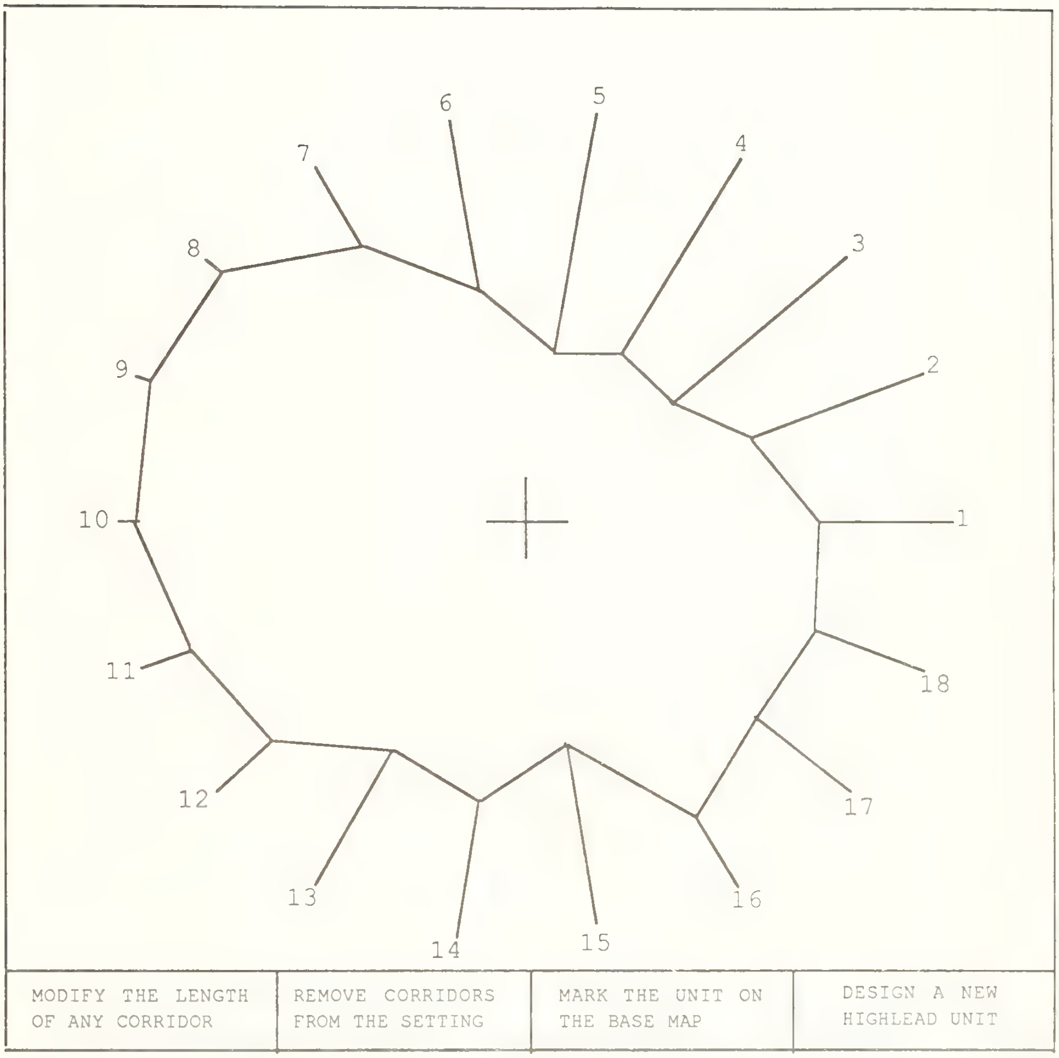


Figure 3—Layout of the highlead unit used in the HIGHLEAD program.

For each of the 18 corridors, the HIGHLEAD program computes the maximum yarding distance over which the yarding equipment can operate without exceeding the line capacity of the yarder and without yarding in a blind lead situation.

A plan-view plot of the area that can be yarded to the landing is displayed on the terminal screen (fig. 4). Next, the planner may choose to modify the yarding boundary by changing the yarding distance for individual corridors or by deleting any of the 18 corridors from the setting.


6
5
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14
15
MODIFY THE LENGTH OF ANY CORRIDOR
REMOVE CORRIDORS FROM THE SETTING
MARK THE UNIT ON THE BASE MAP
DESIGN A NEW HIGHLEAD UNIT

Figure 4—Highlead harvest unit plotted from the HIGHLEAD program.

Changing the yarding distance for a selected corridor—The planner can modify the yarding distance corridor by corridor. The number of the corridor to be modified is entered, and its profile is plotted immediately on the computer screen. The position of the tower and the initial yarding limit are shown on this profile. If the planner wants to extend this limit by tightlining, the location of the tailblock must first be established by setting a cursor on the terrain point selected for the tailblock. The analysis proceeds, and the yarding limit possible with tightlining is shown on the profile with a message explaining why tightlining could not be extended beyond the limit shown.

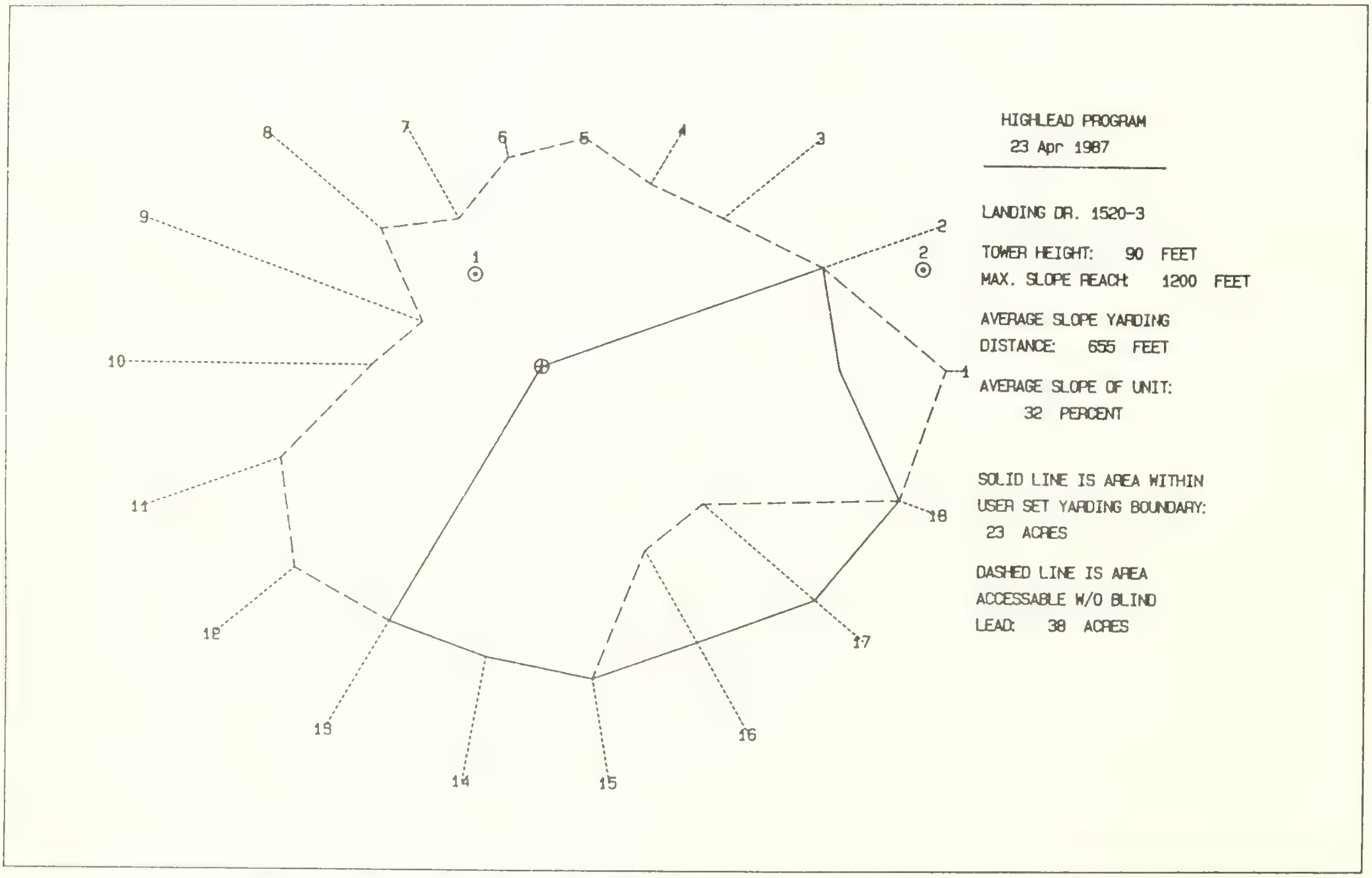
A planner may, on some corridors, plan for the highlead system not to yard to its maximum reach[3] and, consequently, will adjust the yarding limit of those corridors inward. This shortening of yarding distance is done by moving a pointer on the terminal screen to a constrained yarding limit selected at a position on the corridor profile that is inside the maximum yarding limit shown by the program.

---

[3] Some planners, depending on their objective, are concerned only with establishing access to the timber and do not wish to detail their plan to the point of deciding which of several landings that provide yarding access to the timber should be used. If a planner wishes to forecast the harvesting costs for a plan and use an analytical program like SIMYAR to predict yarding costs, then the harvest boundaries should be delineated as correctly as possible to ensure an accurate analysis.

Deleting yarding corridors—The planner may not want the highlead harvest unit to extend around a full 360° circle. The planner may delete those corridors encompassing terrain not to be included in the setting by typing in the numbers of the corridors to be removed.

Transferring the designed highlead harvest unit to the plan—When the design of a unit is completed, HIGHLEAD can produce a map-scale plot of the unit (fig. 5). This plotted drawing can be traced onto the topographic map or to an overlay keyed to the map (with the aid of digitized transfer points marked 1 and 2) to provide a permanent record of the unit design. Both the initial boundary established by direct mainline pull and the boundary resulting from any user modifications are shown on the plot with the acreage included in each boundary, the average slope of the unit, and the average yarding distance.



HIGHLEAD PROGRAM
23 Apr 1987

LANDING DR. 1520-3

TOWER HEIGHT: 90 FEET
MAX. SLOPE REACH: 1200 FEET

AVERAGE SLOPE YARDING
DISTANCE: 655 FEET

AVERAGE SLOPE OF UNIT:
32 PERCENT

SOLID LINE IS AREA WITHIN
USER SET YARDING BOUNDARY:
23 ACRES

DASHED LINE IS AREA
ACCESSABLE W/O BLIND
LEAD: 38 ACRES

Figure 5—Final design of a highlead harvest-unit for transfer to the timber-harvest plan

Analytical Description of the HIGHLEAD Program

The HIGHLEAD program calculates and shows the distance out from the landing accessible for yarding; this is the yarding limit. A point on the topographic map is picked as a promising landing location. When this point is digitized, a network of 18 evenly spaced yarding corridors radiating out from the yarder are plotted in plan-view; each corridor subtends a 20° arc. This defines the initial yarding limit of the setting.

Direct Yarding Limit

This initial yarding limit shows the area from which logs can be pulled directly to the landing by the mainline without the lead angle having to be improved via tightlining. The pull of the mainline is not obstructed by any intervening ground and tends to pull logs across or over the ground rather than into it. Terrain outside the area of direct mainline pull is either in a blind lead area or beyond the maximum reach of the yarding system.

A terrain profile for each corridor is divided (horizontally) into 20 evenly spaced sections comprised of elevations calculated from the DTM for 21 evenly spaced terrain points. The sequence of checking for ground obstructions begins at the terrain point nearest the tower and progresses outward to the maximum reach (limited by mainline length) specified for the setting. If, for example, the maximum yarding reach of a system is specified to be 1,000 feet, the resulting terrain points are 50 feet apart (that is, $1000 \div 20 = 50$). If the terrain point 50 feet out from the tower does not result in a blind lead situation, the next terrain at 100 feet is checked and so forth. When a blind lead situation occurs, the yarding limit is set at the previous terrain point. If no blind lead problems occur in a corridor, the yarding limit is not reached and extends the full length of the mainline reach.

Blind Lead Algorithm

Blind lead has been defined as a condition on those portions of highlead settings where a straight line between a log and the top of the highlead tower intersects the ground. It can be approximated, after the timber is cut, as areas inside the harvest unit where the tower cannot be seen. The HIGHLEAD program calculates the blind lead point in a slightly more conservative manner (fig. 6).

The initial test for highlead feasibility requires that the angle of pull (A_P) be equal to or greater than the angle of the ground (A_G). The A_P of the choker must be at least parallel to the ground or provide a pull that lifts the hooked end of the log from the ground. If the angle is less, the log will be pulled into the ground and a blind lead situation will result. The analysis for highlead yarding used in the HIGHLEAD program assumes that the chokers are fixed to the log at a point 3 feet above the ground. This makes the analysis slightly more conservative because the angle from that point to the head block on the tower is slightly lower than if the chokers were fixed at the ground line.

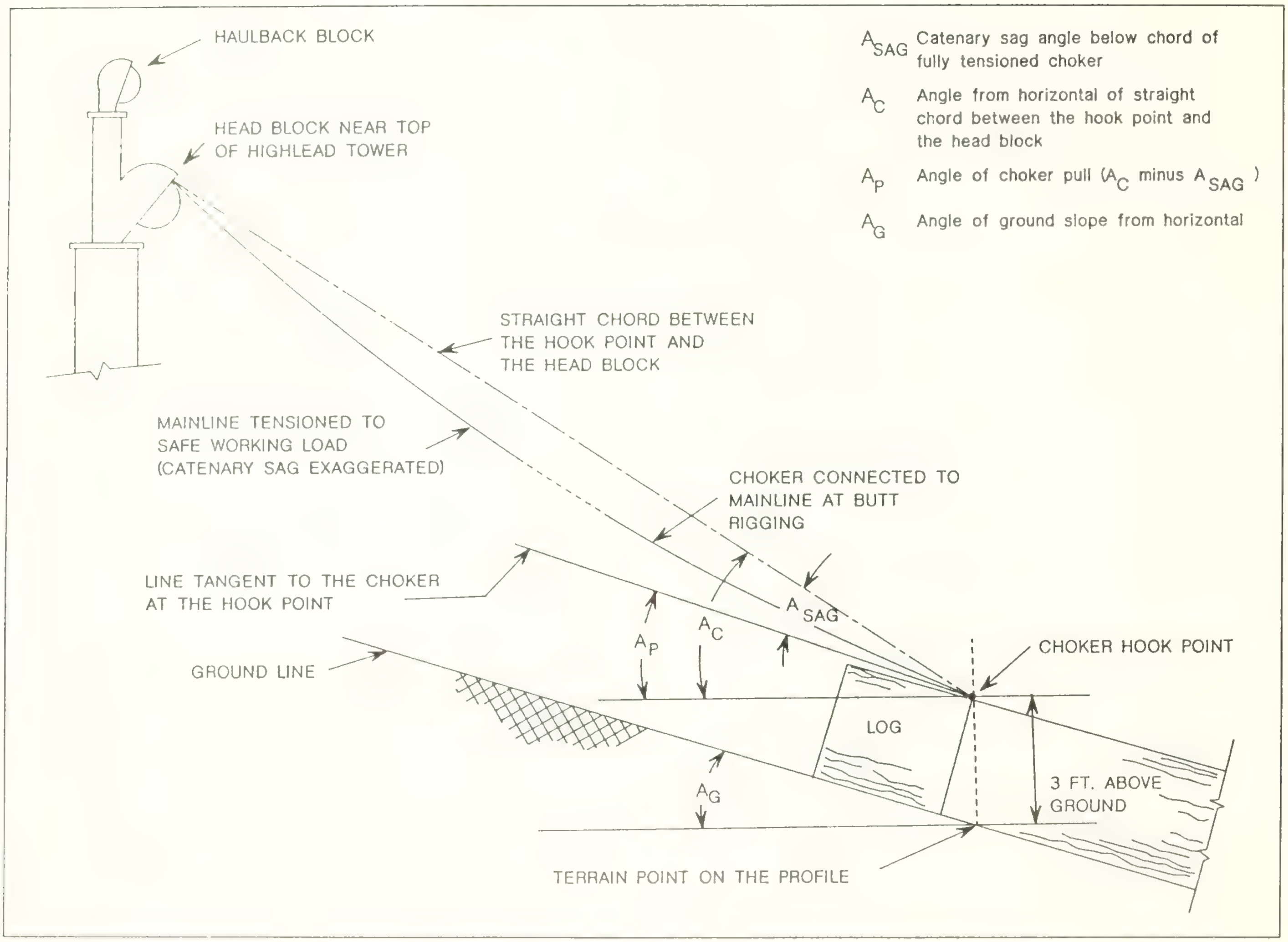

HAULBACK BLOCK
HEAD BLOCK NEAR TOP OF HIGHLEAD TOWER
A_{SAG} Catenary sag angle below chord of fully tensioned choker
A_C Angle from horizontal of straight chord between the hook point and the head block
A_P Angle of choker pull (A_C minus A_{SAG})
A_G Angle of ground slope from horizontal
STRAIGHT CHORD BETWEEN THE HOOK POINT AND THE HEAD BLOCK
MAINLINE TENSIONED TO SAFE WORKING LOAD (CATENARY SAG EXAGGERATED)
CHOKER CONNECTED TO MAINLINE AT BUTT RIGGING
LINE TANGENT TO THE CHOKER AT THE HOOK POINT
A_P
A_C
A_{SAG}
CHOKER HOOK POINT
GROUND LINE
LOG
A_G
3 FT. ABOVE GROUND
TERRAIN POINT ON THE PROFILE

Figure 6—Angles used for determining the yarding limit from direct mainline pull.

Catenary Correction for the Mainline

The vertical angle measured from the choker hook point to the mainline block is corrected in this analysis for the slope, or sag angle, of a tensioned wire rope. This sag angle, described and measured by catenary equations, brings the analysis closer to reality. It is shown as A_{SAG} on figure 6, where the magnitude of A_{SAG} is exaggerated for clarity. Fully tensioned wire ropes approximate straight lines (rigid links) more closely than figure 6 would indicate. The amount of sag for a wire rope tensioned to a safe working load (that is, one-third of predicted breaking strength of extra-improved plow steel) is dependent solely on the horizontal distance from the log to the tower. Solving for the catenary sag angles of a number of different line sizes and spans shows that when the lines are assumed fully tensioned, the angle does not change with line size or slope but only with horizontal distance. The method we used to solve these sag angles required iterative solutions of the transcendental catenary equations presented by Carson (1977). The resulting A_{SAG} can be expressed simply as 0.00155° per foot of horizontal span distance, or 1.55° at a 1,000-foot horizontal span. This constant is used in the HIGHLEAD program and speeds the analysis considerably.

The correction of 0.00155° per foot is not trivial. Its effect can be duplicated by using the standard "line-of-sight" algorithm but shortening the highlead tower to an equivalent adjusted height. If this were done, the tower would have to be shortened from its actual height by over 27 feet at a yarding distance of 1,000 feet, and by over 13 feet at a yarding distance of 500 feet.

Analysis of Tightlining

Once the initial yarding limits are calculated for 18 corridors, the planner may try extending the yarding distance into areas of blind lead by tightlining. The purpose of tightlining is to lift the butt rigging high enough that logs can be skidded to the landing without plowing into or hanging up on the ground. Tightlining analysis in the HIGHLEAD program tests the shape of the ground profile to see if the criteria assumed necessary for successful tightlining can be met. Figure 7 outlines this tightlining algorithm.

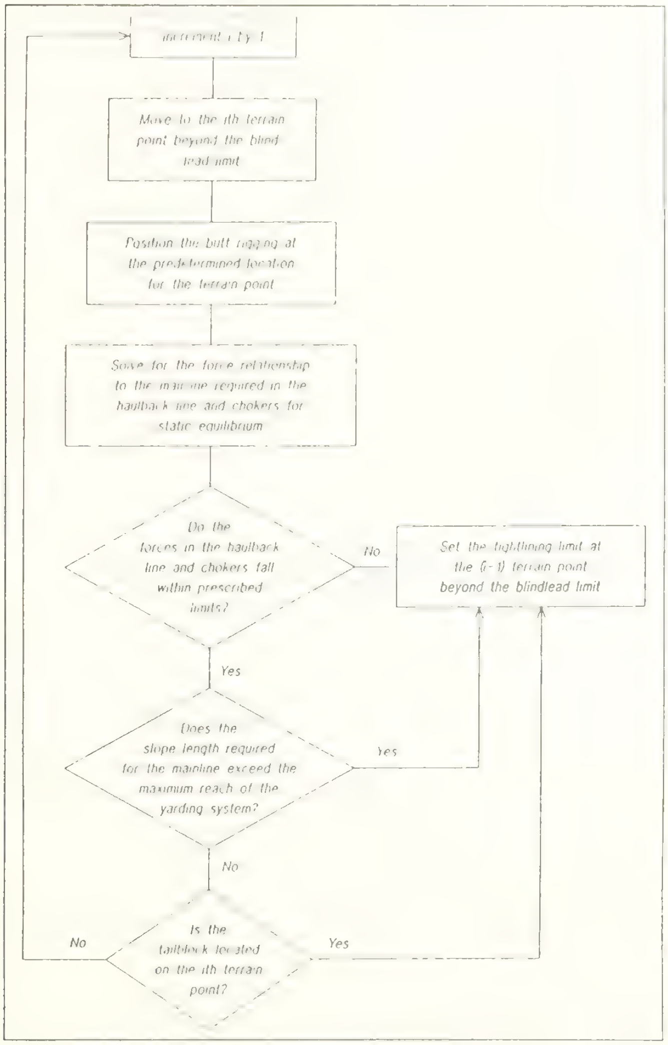

Increment i by 1
Move to the ith terrain point beyond the blind lead limit
Position the butt rigging at the predetermined location for the terrain point
Solve for the force relationship to the mainline required in the haulback line and chokers for static equilibrium
Do the forces in the haulback line and chokers fall within prescribed limits?
No
Set the tightlining limit at the (i-1) terrain point beyond the blindlead limit
Yes
Does the slope length required for the mainline exceed the maximum reach of the yarding system?
Yes
No
Is the tailblock located on the ith terrain point?
No
Yes

Figure 7—Flowchart of the tightlining algorithm.

In general, the algorithm is based on simple, rational assumptions. The results from a force-balance analysis of the three tensioned cables that join at the butt rigging are used to determine whether too much tension is required in the haulback line to hold the butt rigging where the chokers can pull on the logs with sufficient lift to move the load. The details on this assumption follow.

The butt-rigging position establishes the direction of pull on the log. If the butt rigging is close to or on the ground, insufficient upward pull is exerted from the chokers to initiate log movement. A solution for tightlining requires that a specific and critical position of the butt rigging (where the chokers, the mainline, and the haulback line meet), a necessary prerequisite to log movement, be determined. This butt-rigging position depends on the shape of the profile, the log weight, the coefficient of static friction between the log and the ground, and the tension in the various lines. Because log movement can typically occur at many combinations of lead and choker tension, many solutions for tightlining are possible. The tightlining algorithm used in HIGHLEAD does not solve for specific conditions; it only checks whether or not tightlining will succeed. A key assumption in this algorithm is that the butt rigging must be positioned high enough off the ground for its lead to provide a direction of choker pull slightly higher than the slope of the ground. This position is the lowest point the butt rigging can occupy if tightlining is to succeed (fig. 8).

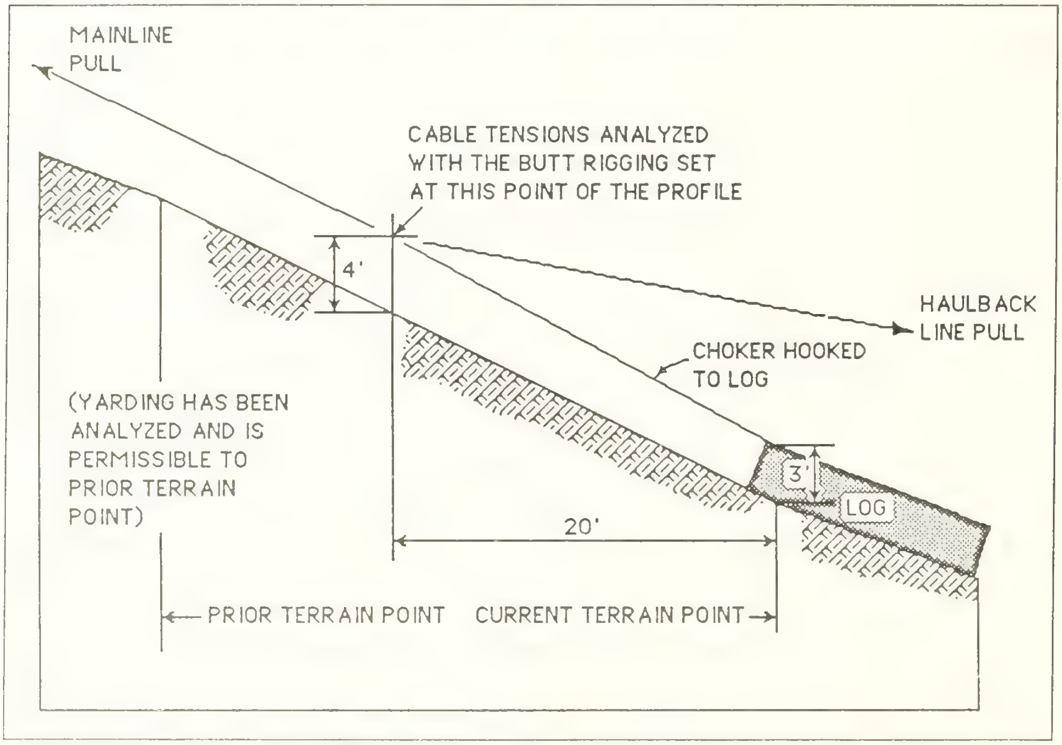

MAINLINE PULL
CABLE TENSIONS ANALYZED WITH THE BUTT RIGGING SET AT THIS POINT OF THE PROFILE
4'
HAULBACK LINE PULL
CHOKER HOOKED TO LOG
(YARDING HAS BEEN ANALYZED AND IS PERMISSIBLE TO PRIOR TERRAIN POINT)
3'
LOG
20'
PRIOR TERRAIN POINT
CURRENT TERRAIN POINT

Figure 8—Position where the butt rigging is initially set when wire rope tensions and the feasibility of increasing the yarding reach by tightlining are analyzed.

The position assigned to the butt rigging is 4 feet off the ground and 20 feet ahead of the log,[4] which results in a near-minimal upward pull angle for the chokers that allows skidding (moving) the logs. It also provides a discrete location needed for solving the forces in the working lines.

---

[4] This position permits a reasonably effective upward pull to be exerted on the log(s) by the chokers 30 feet long (a reasonable choke length for highlead yarding) hooked to a large-diameter log 3 feet (fig. 8) above the ground.

Higher tension in the chokers is required to move the logs when the butt rigging is 4 feet above the ground than when the butt rigging is higher. It is convenient, however, to set a butt-rigging position that is at or near the minimum limit of yarding operability. When generous deflection in the profile permits lifting the butt rigging to positions higher than 4 feet, tightlining becomes easier and success more probable. These results do not conflict with the tightlining algorithm because the algorithm's line-tension criteria are most easily met when the deflection is great. The deflection for the highlead span is greatest when the butt rigging is only 4 feet off the ground. The algorithm will therefore approve tightlining when the deflection is ample. Log movement may begin with low choker tension and at a butt-rigging position higher than 4 feet off the ground, but this would tend to occur because the most efficient angle of choker lead (where minimum pull through the chokers will overcome the forces resisting log movement) is generally when the butt rigging is higher than 4 feet off the ground (see fig. 9).

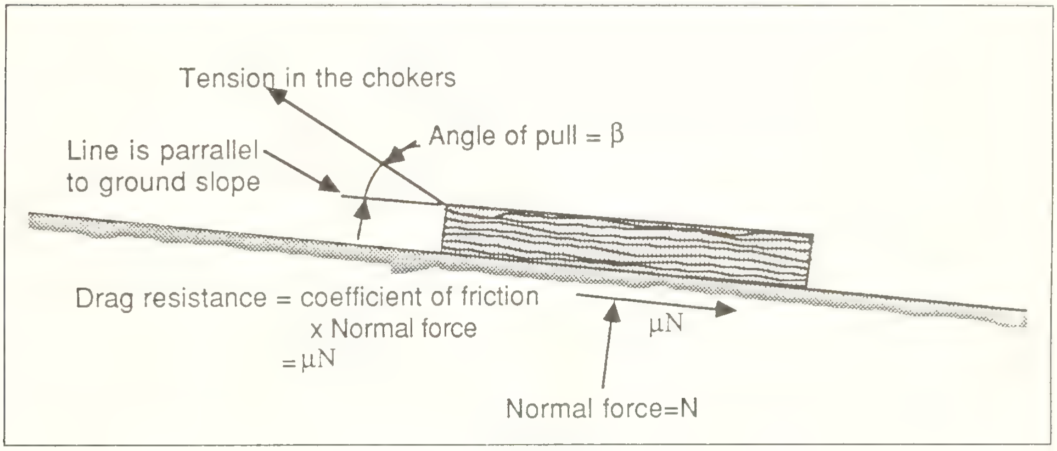

Tension in the chokers
Angle of pull = β
Line is parrallel to ground slope
Drag resistance = coefficient of friction x Normal force = μN
μN
Normal force=N

Figure 9—The most efficient angle is the angle of pull whereby a minimum tension in the chokers is required to move the log. This angle is expressed by ß = Arc TAN μ.

When the coefficient of friction between logs and the ground is between 0.5 and 1.0, the optimum ß angle will range between 26.6° and 45°. If log movement does not occur when the butt rigging is higher than 4 feet, the tension on the mainline can be increased. This will pull the butt rigging to a lower position, which is unfavorable to log movement, but will put a higher tension in the chokers, which is favorable to log movement. In many instances, the increased tension in the chokers will more than compensate for the less effective pulling angle. Therefore this algorithm, which uses a fixed position of the butt rigging, should not negate any feasible tightlining opportunities. Conversely, when the butt rigging cannot be held as high as the assumed point because of poor deflection, the haulback and choker tensions will not meet the criteria of this tightlining algorithm. Even though this 4-foot-high position of the butt rigging might rarely occur, it provides a convenient and reliable method for the analysis of tightlining when it is combined with checks on line tension.

With the butt-rigging position set, the line of action of the force vectors in each of the working lines can be established. The mainline pulls from the butt rigging to the headblock on the tower. The haulback line pulls from the butt rigging to the tailblock. The drop line, or choker, pulls from the butt rigging to the log. The mainline is assumed fully tensioned, and the analysis is based on the relation between the tensions required in the other two lines and the mainline. Three main assumptions govern the tightlining analysis.

1. Tension in the haulback line cannot exceed one-half of the mainline tension. This is based on highlead yarding generally being done with a mainline about twice as strong as the haulback line. A typical West Coast highlead yarder will spool a 1-1/4-inch mainline, which has a safe working strength of 53,300 pounds, and a 7/8-inch haulback, which has a safe working strength of 26,500 pounds. The haulback, in this case, has a safe working strength and a cross-sectional area slightly less than one-half of the mainline. Although other combinations of main and haulback line can be used, the implied two-to-one force ratio is a reasonable planning guideline; the mainline does the real work of pulling the logs in, and the haulback is generally needed only to pull the mainline, butt rigging, and chokers out into the harvest unit. Even when the haulback line must be tensioned during tightlining, it is not practical to allow the tension in the haulback to equal the tension in the mainline. If the horizontal component of the tension in the mainline does not **exceed** the horizontal component of the tension in the haulback, no tension will be available in the chokers for hauling in (yarding) logs.

2. Tension in the drop line (choker) must be at least one-half of the mainline tension. This assumption, a corollary of the first, ensures that at least half of the pull from the mainline is transmitted into the chokers to pull the log towards the landing. The reasons for limiting the haulback tension to less than one-half of the mainline tension also apply to requiring the dropline tension to be at least one-half of the mainline tension.

3. Tension is the only force permitted in the lines. This assumption provides a necessary restraint on the analysis. Wire ropes can act only as tensile structural members. Any force-balance solution meeting the requirements of static equilibrium by assigning a compressive force in a wire rope is automatically rejected.

Two additional assumptions control tightlining analysis but do not relate to line tensions.

4. The yarding limit for tightlining cannot move as far out as the tailblock, but is limited to the terrain point immediately in front of the tailblock. This assumption is necessitated by the tightlining algorithm. If the force vectors to be analyzed for the tightlining solution are established with the log at the same terrain point as the tailblock, the spatial arrangement invalidates the algorithm because the log and the tailblock cannot occupy the same space. Harvest planners should be aware that restricting the yarding limit resulting from tightlining to the terrain point in front of the tailblock will not necessarily constrain the highlead system from yarding up to the tailblock.

5. The yarding limit for tightlining cannot be set at a slope distance from the tower that is beyond the reach of the highlead mainline. This final assumption provides a way to ensure that the yarding limit will not be set at a point beyond the reach of the mainline. The initial direct-yarding-limit analysis encompassed a circle with a horizontal radius set equal to the maximum slope-yarding distance of the system. The tightlining analysis restricts reach in blind lead areas by imposing a slope-distance constraint on the reach of the mainline.

Examples of Tightlining

Designing to increase yarding distance through tightlining is done profile by profile. The planner chooses the profile to be examined for tightlining and then must choose a location and rigging height for the tailblock on the profile. This location should be selected to take advantage of whatever lift the terrain permits. With these inputs, the tightlining analysis proceeds automatically. It begins one terrain point beyond the terrain point labeled as the yarding limit, based on direct mainline pull; this is the first terrain point where the blind lead situation occurred. The routine analyzes that terrain point for tightlining operations. If tightlining criteria are met at that terrain point, the analysis moves one more terrain point out from the yarder and repeats the analysis for the new point. The example in figure 10 shows tightlining analysis at a point where tightlining meets the criteria of the algorithm.

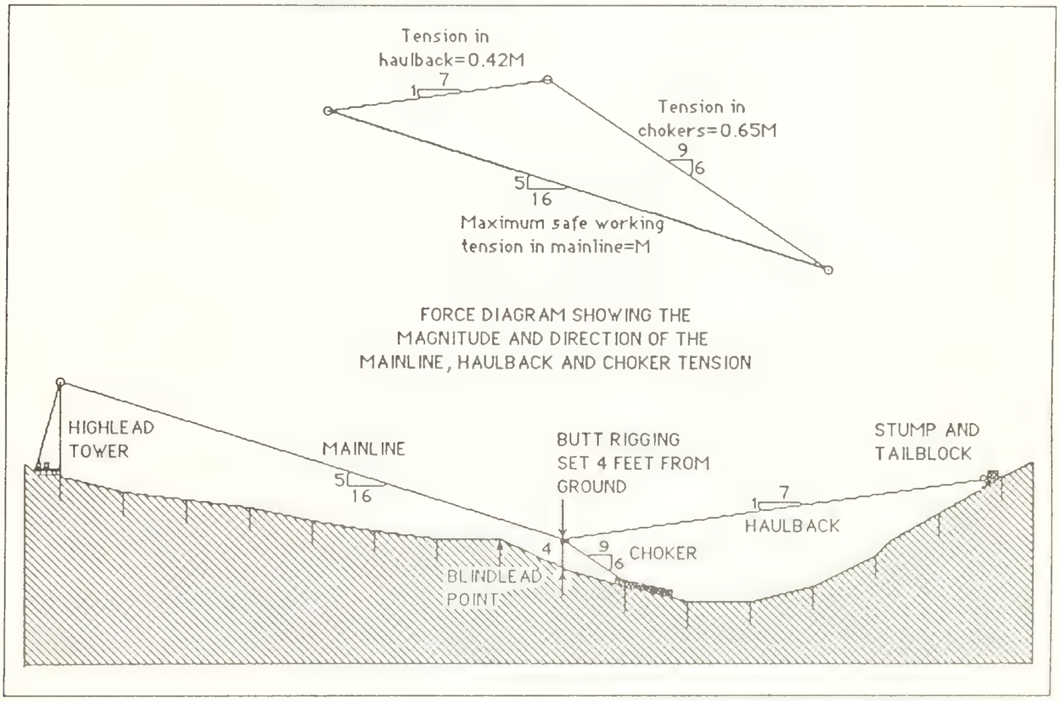

Tension in haulback=0.42M
1
7
Tension in chokers=0.65M
9
6
5
16
Maximum safe working tension in mainline=M
FORCE DIAGRAM SHOWING THE MAGNITUDE AND DIRECTION OF THE MAINLINE, HAULBACK AND CHOKER TENSION
HIGHLEAD TOWER
MAINLINE
5
16
BUTT RIGGING SET 4 FEET FROM GROUND
STUMP AND TAILBLOCK
1
7
HAULBACK
4
9
6
CHOKER
BLINDLEAD POINT

Figure 10—Profile of a situation where tightlining meets the choker and haulback tension requirements of the algorithm.

The force diagram above the profile indicates that the haulback tension is less than half (42 percent) and the choker tension is greater than half (65 percent) of the mainline tension, as required. This analysis continues until a terrain point is encountered where one or more of the five criteria are not satisfied. When this point is encountered, a message is printed at the last terrain point meeting the tightlining criteria. The message indicates how far along the profile tightlining is feasible and indicates which criteria were violated beyond the displayed yarding limit.

Figure 11 shows where tightlining cannot extend the yarding limit beyond the blind lead point. Here the haulback line is overstressed (at 58 percent of mainline tension). Sufficient tension for yarding can pass from the mainline to the chokers, so only the overstressed haulback prevents tightlining success. In this situation, the blind lead point

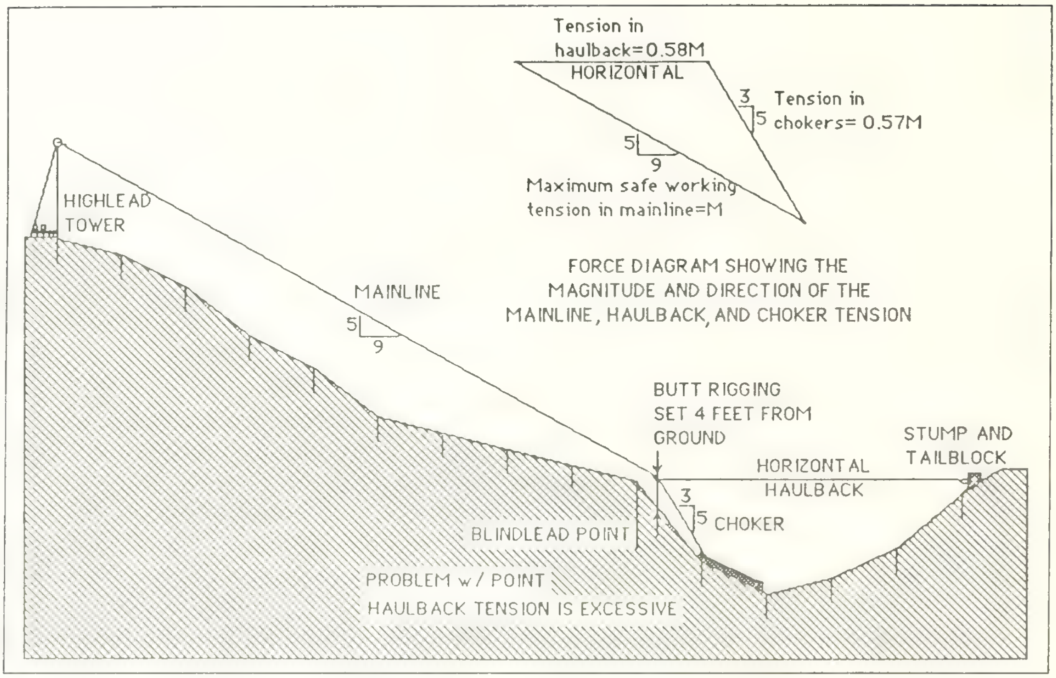

Tension in haulback=0.58M
HORIZONTAL
3
5
Tension in chokers= 0.57M
5
9
Maximum safe working tension in mainline=M
HIGHLEAD TOWER
MAINLINE
5
9
FORCE DIAGRAM SHOWING THE MAGNITUDE AND DIRECTION OF THE MAINLINE, HAULBACK, AND CHOKER TENSION
BUTT RIGGING SET 4 FEET FROM GROUND
STUMP AND TAILBLOCK
HORIZONTAL HAULBACK
3
5
CHOKER
BLINDLEAD POINT
PROBLEM w / POINT
HAULBACK TENSION IS EXCESSIVE

Figure 11—Profile of a situation where the haulback tension is too high to meet the requirements of the tightlining algorithm.

(called the "direct mainline pull yarding limit" on the program's output) is also the yarding limit with tightlining, which shows that tightlining cannot increase yarding reach on this profile.

Tightlining under the conditions shown in figure 12 is difficult to impossible. Here the haulback line is overstressed, and the chokers are understressed.

Planners using HIGHLEAD learn to recognize whether tightlining will or will not work. Straight or convex ground profiles, which are poor for skyline yarding, provide little possibility for successful tightlining. The situation above (fig. 12) typifies a tug of war between the haulback and mainline, where too little (42 percent) of the mainline's tension passes into the drop line and too much (61 percent) into the haulback line.

Figure 13 shows a situation in which the tailblock is positioned on the profile at a point where lift through tightlining is impossible. When the algorithm can solve the force system only by assigning negative tension to either the chokers or the haulback, a message indicating that no lift is possible from tightlining is displayed. Negative tension, as defined here, is compression—a force impossible to develop in wire ropes.

These tightlining examples plotted in profile view show and emphasize that lift (deflection) is as important for highlead yarding as for skyline systems.

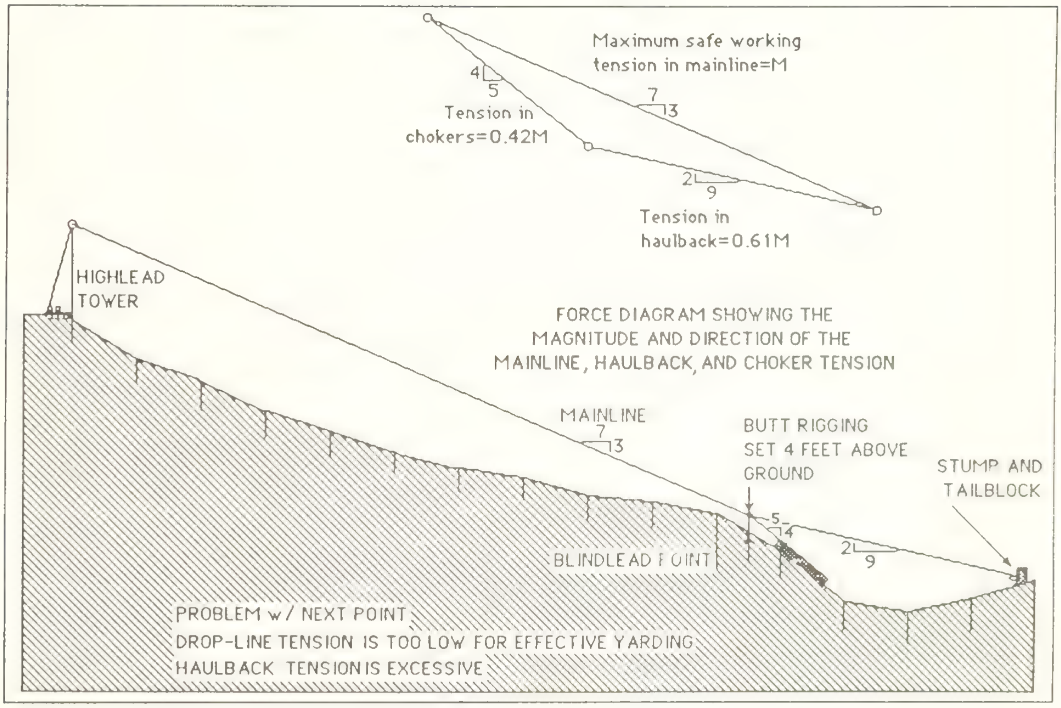


Figure 12—Profile of a situation where the haulback tension is too high and the choker tension is too low to meet the requirements of the tightlining algorithm.

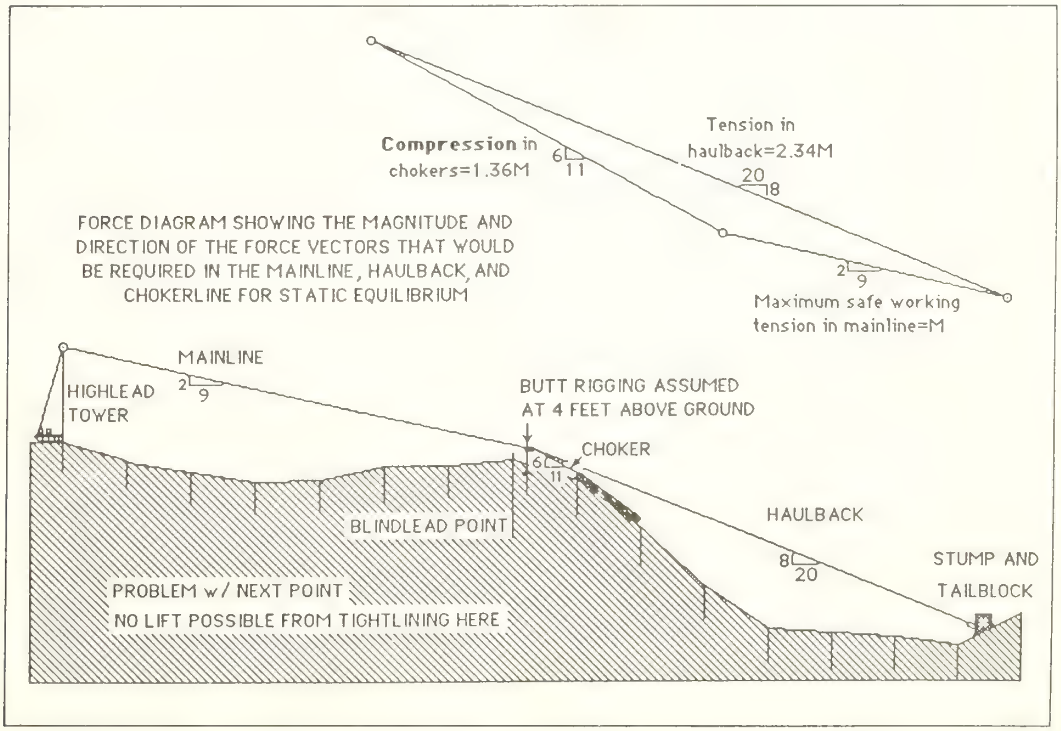


Figure 13—Profile of a situation where tightlining is impossible because the algorithm solved the force triangle by assigning a compressive force to one of the cables.

Limitations

Smoothed, uniform ground profiles extracted from the DTM may not analytically restrict yarding to the extent representative of actual ground conditions and therefore could limit the usefulness of the HIGHLEAD program. In actual field conditions, short adverse pitches, dips, rocks, stump butt swells, and terrain irregularities typically occur to impede log movement but are conspicuously missing from extracted profiles. These irregularities can become major obstructions for highlead yarding, yet accounting for them on timber-harvest plans in a way that is both analytically correct and practical is difficult.

The yarding system can be strained and possibly overtaxed if, when log movement begins, the log is pulled immediately into an obstruction. When the log is already moving with sufficient velocity, it may be able to push through and obliterate potential obstructions. Past logging often shows where skidded logs have pushed or plowed through obstructions. Such skidtracks develop a trough that permits easier passage of the next logs. Because all potential obstructions do not cause hangups, the field irregularities in the analyses can be partially ignored.

Payload

The HIGHLEAD program does not produce a payload analysis for the yarding corridors of the designed harvest unit. This makes the program inconsistent with other cable-logging design programs for skyline yarding systems, which usually include a payload analysis. One reason for ignoring payload calculations in the HIGHLEAD algorithm is that payload for highlead depends on the coefficient of friction between the log and the ground, which in turn depends on several variables beyond the level of complexity needed for area planning. Furthermore, maximum physical payload for highlead yarders is generally so ample that the actual payload hooked is seldom limited. Other factors, such as the number of chokers, the number of logs within reach of the chokers, and log size, will normally limit the log turn to a weight less than maximum physical payload. The yarding limit determined by the mainline pull angle is therefore the most critical variable in planning highlead harvest units.

Maximum physical payload for highlead yarding can be approximated by assuming a coefficient of log-drag friction, which will range between 0.5 and 1.0 for logs with bark on bare ground; it will differ with log species and diameter, soil texture and moisture content, and slope (Henshaw 1977). If a conservatively high coefficient of log-drag friction of 1.0 is assumed, and it is also assumed that the logs are on level ground (where slope[5] does not affect the payload) and the choker pull is parallel to the ground slope, then when the pull in the choker exceeds the log weight log movement will begin. Once movement begins, the magnitude of the log-drag force will be reduced because the resistance from kinetic (moving) friction is lower than resistance from static (stationary) friction. This will, in turn, permit a higher proportion of the choker tension to increase the acceleration of the log toward the yarder. The safe working tension of the mainline is roughly equivalent to the highlead payload on level ground. The highlead payload should be multiplied by the reciprocal of the sine plus the cosine of the ground-slope angle when the yarding is being done uphill (for example, the payload is 71 percent of the safe tension in the mainline on 100-percent ground slopes).

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[5] Whether the log is yarded uphill or downhill has a considerable effect on the tension required. For example, on a 80-percent slope with a coefficient of friction of 1.0, a 1,406-pound force is needed to begin moving a 1,000-pound log uphill. Yarding it downhill would only take a 156-pound force.

A nominal and realistic payload must be assigned to evaluate cable-yarding costs in SIMYAR, the yarding-simulation program in PLANS. Payload is constrained by the pull exerted through the mainline drum. Theoretically, the mainline in the HIGHLEAD can be any diameter, but from a practical standpoint it is usually between 3/4 and 1-3/8 inches; the haulback is about one-half of the weight and strength of the mainline. Table 1 lists payloads for HIGHLEAD based on mainline size and pull. The program assumes these payloads are being yarded uphill on 100-percent slopes and the accelerating force from mainline pull is 1,000 pounds greater than the forces resisting log movement. For tightlining, the HIGHLEAD algorithm requires that at least one-half of the tension from the mainline be transmitted to the chokers; therefore, the payloads for tightlining are based on a choker tension one-half that of the direct mainline tension.

Table 1—Maximum highlead payloads for various combinations of main and haulback lines assuming that (1) the mainlines will be stressed to their safe working tension, (2) the coefficient of log-drag friction is 1.0, (3) the logs will be yarded up a 100-percent slope, (4) the extra pull exerted through the mainline exceeds the resisting forces by 1,000 pounds, and (5) the choker pull exerted via tightlining is limited to one-half of the choker pull attained by direct highlead yarding

			Maximum highlead payload	
Mainline diameter	Haulback diameter	Ratio of mainline to haulback weight	Direct highlead pull	Tightlining
Inches			*Kips*	
1-3/8	1	1.89:1	44.5	21.9
1-1/4	7/8	2.04:1	37.0	18.1
1-1/8	3/4	2.25:1	29.9	14.6
1	3/4	1.78:1	23.7	11.5
7/8	5/8	1.97:1	18.0	8.7
3/4	1/2	2.26:1	13.2	6.2

Tightlining

Many loggers prefer to rig highlead yarders as a running skyline (referred to as a "Grabinsky") to yard areas where direct highlead yarding is difficult because of poor lift. This system (see fig. 14) is superior to tightlining with conventional highlead rigging on corridors where lift is needed because the haulback line is twice as effective in supplying lift to the butt rigging. This improvement in lift does not further reduce the effectiveness of the mainline for moving the logs to the landing because the additional lift is supplied totally by the haulback line. The analysis with HIGHLEAD does not, however, address this preferred system.

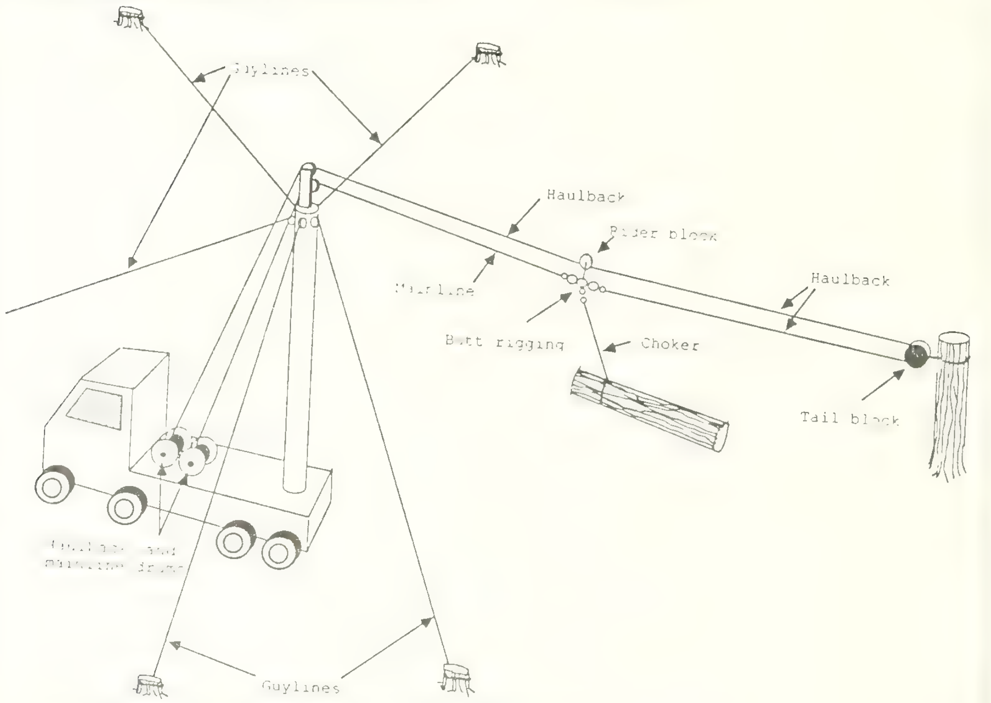

Figure 14—Highlead yarder rigged as a Grabinsky skyline.

For the planner wishing to make exact harvest unit designs that take into account the differences between the operating limits of tightlining and Grabinsky yarding, we recommend analyzing the Grabinsky access limits by using the running skyline option (SKYTOWER; Twito and others in press) in the PLANS program. Entering a small carriage clearance (4 to 6 feet) and payload[6] (1 to 3 kips) will approximate Grabinsky requirements.

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[6] The actual highlead payload would be heavier than this; with highlead yarding, the log is not suspended from the carriage as in skyline systems but is fully supported by the ground.

We recommend using the HIGHLEAD tightlining option to determine which areas of the harvest unit cannot be accessed by direct highlead pull but relying on the Grabinsky skyline to ensure that yarding can be accomplished. Any unit requiring a high percentage of its area to be tightlined should, in fact, be yarded by a Grabinsky, which is easier on the equipment and the site than are conventional highlead tightlining operations.

Another skyline option often used to alleviate blind lead problems is the shotgun (flyer) method. This option, even though often used with highlead yarders, is definitely a skyline system that can also be analyzed with SKYTOWER. When the yarding is uphill with the skyline slopes sufficient to permit outhaul of the carriage by gravity and good anchoring available, this option should be considered.

Conclusions

Cable loggers know that, whether they use a skyline or highlead system, the ability to operate depends on the ability to lift the logs. Most of the effort for assuring that needed lift is available has been expended in analyzing of skyline yarding systems, even though highlead is the predominant yarding system in the Pacific Northwest. This HIGHLEAD program, although not the first addressing this subject, is a pioneer in analyzing how the coverage can be extended via tightlining. The program works quickly and conveniently by using DTM data to arrive at highlead settings well adjusted to the topography.

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 pound = 0.4536 kilogram

1 kip = 453.59 kilograms

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Operating Instructions and Worked Examples

An appendix to this report containing step-by-step operating instructions for the HIGHLEAD program is available from the Pacific Northwest Research Station. A copy of this appendix can be obtained by photocopying this page, filling in the necessary information, and sending it to:

USDA Forest Service
Pacific Northwest Research Station
Forestry Sciences Lab
Forest Engineering Systems
4043 Roosevelt Way NE
Seattle, WA 98105

(206) 442-7814

This appendix includes an example of designing highlead harvest units and demonstrates many of the options and manipulations available.

If you wish to receive the PLANS program set—which includes HIGHLEAD—stored on diskettes, send five 5-1/4-inch double-sided, double-density, flexible mini discs.

Please send supplementary material for the HIGHLEAD program to:

NAME ____

ADDRESS ____

____

CITY____

STATE & ZIP CODE__________________________________

Twito, Roger H.; Reutebuch, Stephen E.; McGaughey, Robert J. 1988. The HIGHLEAD program: locating and designing highlead harvest units by using digital terrain models. Gen. Tech. Rep. PNW-GTR-206. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

PLANS, a software package for integrated timber-harvest planning, uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. HIGHLEAD, an integral program in the PLANS package, is used to design the timber-harvest units to be yarded by highlead systems. It solves for the yarding limits of direct mainline pull to the top of the tower by assuming that the angle of pull must be equal to or higher than the slope of the ground. The ground is sampled through a system of 18 uniformly spaced corridor profiles that radiate from user-selected landing locations and that are extrapolated from the digital terrain model. HIGHLEAD permits the planner to reduce the yarding coverage by shortening yarding distance on individual corridors or by deleting portions of the yarding circle. Conversely, the planner can try to extend the yarding distance on individual corridors by tightlining. The algorithm for tightlining is explained as are limitations of the analysis and interpretations on the maximum, safe log load for highlead systems. A guide giving detailed operating instructions for the program is available from the authors.

Keywords: Timber harvest planning, computer programs/programing, logging operations analysis/design, road building (forest/logging).

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PNW-GTR-207

A Key to Arboreal Spiders of Douglas-Fir and True Fir Forests of the Pacific Northwest

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Abstract

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This illustrated key for identifying spiders inhabiting true fir and Douglas-fir is based on extensive collections from throughout the three North American Pacific Coast States. Details of the age classes present at budburst and the season in which to expect adults are presented for all species. This paper is written for people unfamiliar as well as familiar with spider taxonomy; a glossary of all technical terms is included. References to pertinent technical literature are also included.

Keywords: Keys (spider), spiders, Douglas-fir, true fir, Pacific Northwest.

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Introduction

An intensive study of the population dynamics and arthropod associates of larval Douglas-fir tussock moth, (*Orgyia pseudotsugata* (McDunnough)), was conducted from 1976 to 1981 in the El Dorado National Forest, California. Arthropod predation on early instars of this moth has been documented as a key factor in intergeneration survival (Dahlsten et al. 1977; Mason 1976, 1981; Mason and Overton 1983; Mason et al. 1983). The lack of consolidated information on the identity and biology of arboreal spiders, the most abundant arthropod predators in this system, led to development of this key.

Study of the arthropod inhabitants of the Coniferous Biome of the montane Pacific Slope, in cooperation with D.L. Dahlsten, University of California, Berkeley, and R.R. Mason, USDA Forest Service, La Grande, Oregon, revealed that the arboreal spider fauna of the Pacific Northwest is not diverse. Of the more than 500 samples taken from the 15 most abundant tree species throughout this three-State region (more than 100,000 spiders), only 55 species ever constituted more than 5 percent of the total spider population at any site. Most arboreal spiders in this region belong to about 30 abundant, widespread species; only about 150 species were ever collected.

In 1976-77, Dahlsten began intensive sampling of *Abies concolor* in El Dorado National Forest. One-third of the branches of each of 20 trees were individually cut at the bole and all arthropods removed. Species were identified in the field by many people who referred to a simplified synoptic series prepared by C. Griswold. Preliminary results of this study are presented in Dahlsten et al. (1977, 1978).

During 1979-81, eight randomly selected plots were sampled; each plot contained 10 permanently marked 12-m white fir on each of two to four ridges. After dispersal of first-instar tussock moth at budburst, two branches were removed from low, mid, and high canopy of each tree and beaten over a ground cloth. Spiders were preserved, identified, and analyzed for predation on tussock moth larvae (Fichter 1984). In 1981, the relative abundance of spider species on different tree genera and shrubs were analyzed at budburst and again in late fall; these specimens were preserved for permanent reference.

Oregon spider studies were initiated in spring 1981 at McDonald State Forest in the Coast Range and the H. J. Andrews Experimental Forest in the Cascade Range. Monthly samples were gathered to assess the turnover of species through the year, plant-habitat choice, and the relative abundance and constancy of each species from year to year. In 1982, these studies were expanded to include coastal forests and the forests of the eastern slope of the Cascade Range and the Blue Mountains. The results of these samples are presented in table 1. Research on tussock moth by R.R. Mason resulted in spider samples from the montane Great Basin, including southern British Columbia to southern Oregon.

Table 1—The frequency of occurrence and relative abundance of spiders collected from Douglas-fir and true firs in all seasons throughout the Pacific Northwest and their average density at budburst for 3 years on *Abies concolor* in El Dorado National Forest, California [1]

Family, genus, and species	Occurrence	Samples with over 5-percent relative abundance [2]	Density per square meter [2]
	Percent	*Percent*	*Number*
ANYPHAENIDAE:			
Anyphaena pacifica	70	16	0.91
ARANEIDAE:			
Araneus gemmoides	76	4	0.18
Araneus saevus	27	1	0.03
Araniella displicata	69	11	0.09
Cyclosa conica	68	5	0.03
Metepeira grandiosa	4	+	+
Nuctenea patagiata	15	5	–
Tetragnatha versicolor	84	38	0.02
CLUBIONIDAE:			
Cheiracanthium sp.	8	0	+
Clubiona canadensis	31	5	0.01
DICTYNIDAE:			
Dictyna peragrata/uintana	67	30	0.01
Mallos pallidus	5	0	0.05
GNAPHOSIDAE:			
Sergiolus montanus	12	0	0.05
LINYPHIIDAE:			
Bathyphantes spp.	15	5	–
Ceraticelus atriceps	36	14	–
Erigone spp.	6	3	–
Frontinella communis	8	3	–
Gnathantes ferosa	47	29	3.37
Neriene digna	23	1	–
Neriene litigiosa	13	1	0.15
Pityohyphantes brachygynus	59	45	0.90
Pityohyphantes rubrofasciata	53	31	–
Spirembolus mundus	30	18	–
Miscellaneous Micryphantinae	50	11	+
OXYOPIDAE:			
Oxyopes scalaris	38	13	+

See footnotes at end of table.

Table 1—The frequency of occurrence and relative abundance of spiders collected from Douglas-fir and true firs in all seasons throughout the Pacific Northwest and their average density at budburst for 3 years on *Abies concolor* in El Dorado National Forest, California[1] (continued)

Family, genus, and species	Occurrence	Samples with over 5-percent relative abundance[2]	Density per square meter[2]
	Percent	*Percent*	*Number*
PHILODROMIDAE:			
Apollophanes margareta	56	3	0.55
Philodromus rufus pacificus	89	39	0.47
Philodromus speciosus	62	23	0.08
Philodromus spectabilis	80	23	0.51
Philodromus spp.	28	6	+
Tibellus oblongus	4	+	+
SALTICIDAE:			
Eris marginata	10	1	–
Metaphidippus aeneolus	94	69	1.30
Metaphidippus watonus	16	2	0.08
THERIDIIDAE:			
Dipoena nigra	67	13	0.01
Euryopis formosa	6	+	0.02
Enoplognatha ovata	6	0	–
Theridion californicum	20	+	–
Theridion crispulum	10	+	–
Theridion differens	36	7	+
Theridion lawrencei	77	34	0.08
Theridion murarium	21	6	0.01
Theridion neomexicanum	16	0	0.13
Theridion sexpunctatum	20	9	–
THOMISIDAE:			
Misumena vatia	18	0	0.01
Misumenops celer	16	0	0.02
Tmarus angulatus	9	+	0.01
Xysticus locuples	29	+	0.44
ULOBORIDAE:			
Hyptiotes gertschi	34	4	+

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[1] Number of spiders collected at El Dorado in 3 years (over 1100 m^2 of foliage examined) was 11,000. Number of spiders collected throughout the rest of the Pacific Northwest, in 221 separate collections, was 40,000.

[2] + = present but rare; – = not collected.

This key is designed for persons unfamiliar with spider taxonomy. Technical terminology has been kept to a minimum; necessary terms are diagramed in figure 1 and explained in the glossary. Rough identifications can be made using the pictures and notes provided. Though many species vary in color pattern, especially when specimens from extremes of the range are compared, color and pattern are useful discriminators for localized studies. Adult females and immatures often look similar; mature males, distinguished by enlarged copulatory palps, are frequently different in size, shape, and pattern. Species included are reasonably sized immatures and adults found on Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true fir, *Abies* spp. Rarely collected species have not been included in the couplet format but are discussed in the comments. Genitalia of mature specimens are usually necessary for positive identification; instances of similar cohabiting species are noted, but genitalia are not illustrated.

Convenient sources of additional information on taxonomy and natural history are *American Spiders* (Gertsch 1979), *How To Know the Spiders* (Kaston 1978), and *Handbook for Spider Identification* (Roth 1986, printed privately and available from the American Arachnological Society, Department of Entomology, University of Florida, Gainesville, Florida).

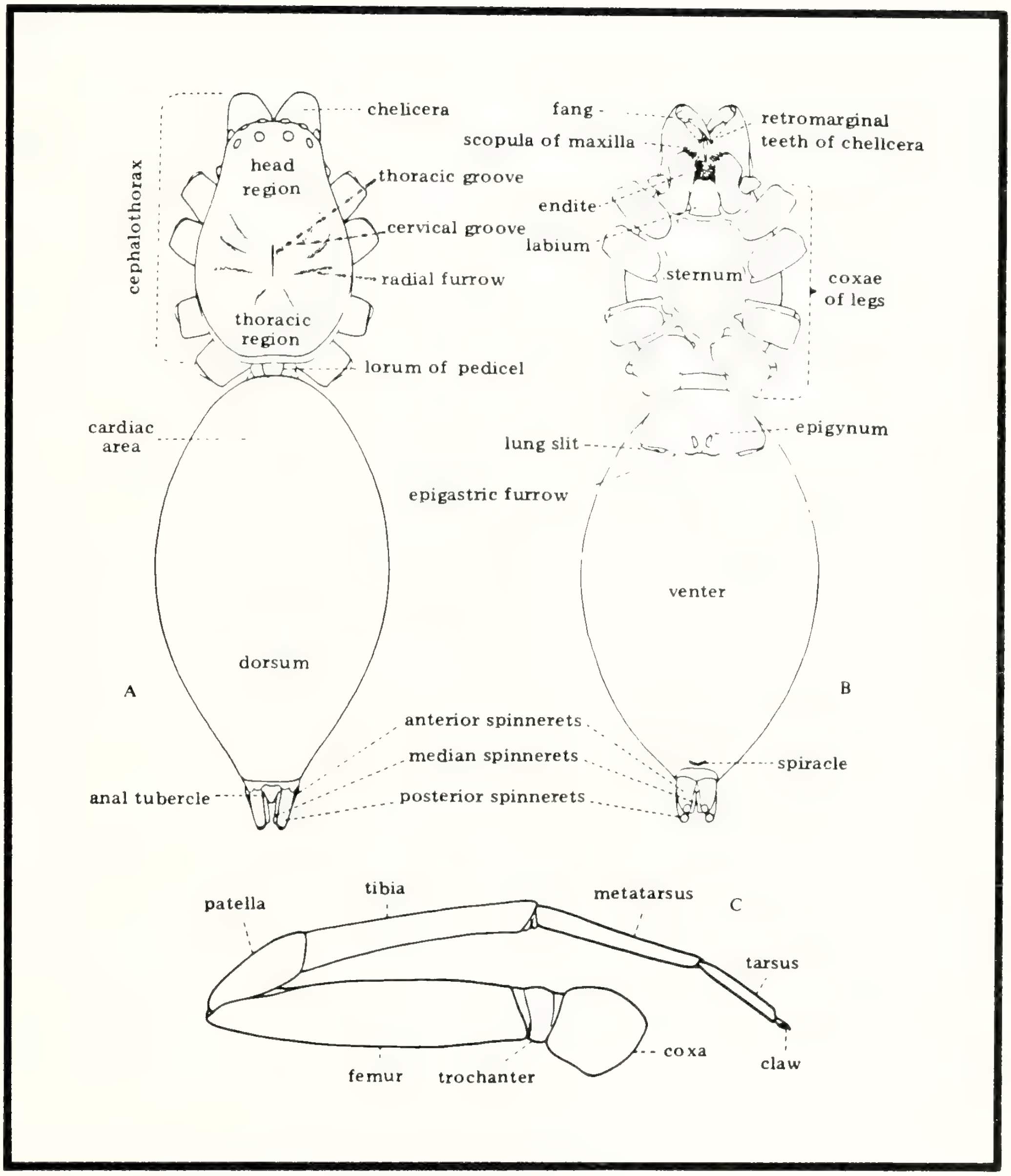


Figure 1--Female spider; dorsal view (A), ventral view (B), leg segmentation (C).

Key to the Genera of Arboreal Spiders

1A Eyes differentially enlarged, two pairs of eyes huge (figs. 2 and 3) 2

1B Eyes subequal (fig. 4) 3

2A Two pairs of forward-directed huge eyes (fig. 3); body elongate; height of abdomen never distinctly greater than that of cephalothorax; legs short, robust (the jumping spiders; plates I, J) . . . . see key, p. 35

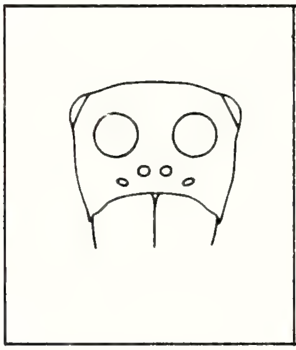


Figure 2—Eye arrangement of the Lycosidae. Note the four small anterior eyes and the enlarged posterior row, two of which are directed anteriorly and two laterally.

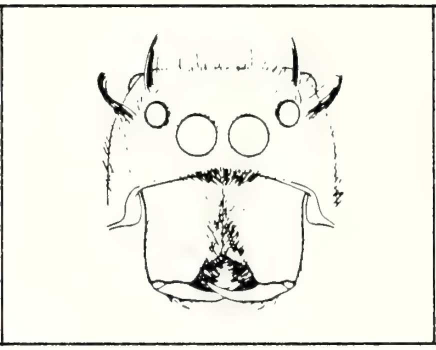


Figure 3—Eye arrangement in the Salticidae. Note the enlarged anterior row, all four directed forwards, and the posterolateral enlarged pair pointing laterally.

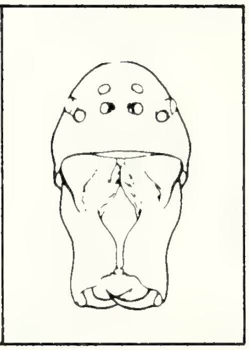


Figure 4—Eye arrangement of the more typical spider, as exemplified by *Dictyna;* note the curved chelicerae (A) of the male.

2B Two pairs of huge eyes, one directed forward over row of four small eyes and one directed laterally (fig. 2; plate B: 8) . . . . Lycosidae

Many species of this abundant, ground-dwelling family are present in El Dorado National Forest. Only small immatures of unknown species are collected, infrequently, from trees.

3A First two pairs of legs held parallel to substrate and usually distinctly longer than last two pairs; legs laterigrade, that is, with the morphologically anterior surface directed dorsad (crab spiders) (plates K, L) . . . . see key, p. 39

3B All legs held principally in the vertical plane; legs prograde, the morphologically anterior surface directed anteriorly 4

4A Six equal-sized eyes arranged in a hexagon (the anteromedial pair very small and inconspicuous, clypeus very high; fig. 5); abdomen pointed posteriorly; legs with prominent spines . . . . Oxyopidae

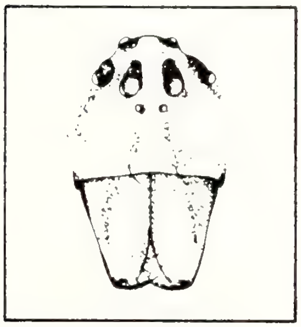


Figure 5—Face and chelicerae of *Oxyopes scalaris.*

Only *Oxyopes scalaris* (plate L: 7) is native to this region. (*Oxyopes salticus,* native to the Eastern and Central United States, is encountered infrequently in disturbed regions; it has distinct black lines on the ventral surfaces of femora I and II.) This species, more frequently found in shrubs than in trees, has comprised more than 40 percent of spiders from early regrowth conifers. Adults are polymorphic in color pattern and are most abundant in June, with many adult females lasting through July. Adults are fast runners and jumpers, attaining a body length of 5 to 8 mm; in spring, immatures 2.0 mm in length are also present.

4B Eyes not in hexagonal pattern, many other patterns possible 5

5A Height of abdomen greater than width; legs usually several times length of body and thin; abdomen often largely white, with or without a median dorsal longitudinal band . . . . Linyphiidae (in part)

A. Abdomen white, with or without median contrasting band . . . . B

AA. Abdomen orange-brown with contrasting black longitudinal median band and subadjacent chevrons . . . . *Pimoa altioculata*

B. Carapace with median, anteriorly pointed Y-shaped band C

BB. Carapace unmarked; legs bright yellow, without black maculations; midline of venter not darkened; cuticle of abdomen without markings (except for tenuous gray midline in some adult and subadult males) but reflective (not shining in latter species) with numerous small spherical white deposits under cuticle . . . . *Gnathantes ferosa*

C. Legs with black maculations along entire length; abdomen of submatures with a wide, brownish-black and evenly wavy band . . . . *Pityohyphantes brachygynus*

CC. Legs with pale red bands; abdomen with wide, purplish-red evenly wavy band . . . . *Pityohyphantes rubrofasciata*

Several species of *Pimoa* live in the Western United States, but only *P. altioculata* (plate C: 6) has been found arboreally. Though an abundant species, it occurs only rarely in the canopy and then in old growth.

Gnathantes ferosa (plate D: 2) is consistently one of the most abundant arboreal spiders. It is small (2.0-2.5 mm body length at maturity); males are present in September, females principally in October. It is easily confused with more lightly colored immature *Pityohyphantes.* By mid-July, most submales have cream-colored bulbous palps half the size of the cephalothorax, which distinguish them from immatures of other species that are much larger when palps start to enlarge. Little growth occurs between immatures at budburst and fall adults. The height of the abdomen is noticeably greater than its width only in adults and subadults. Smaller immatures will key to 22A.

Pityohyphantes, a very diverse genus in North America, has not been revised recently. Though several species occur in abundance throughout forests of the Pacific States, only *P. brachygynus (=P. costatus* in Dahlsten et al. 1978) has been collected in our El Dorado and Stanislaus National Forest studies. Larger individuals of this species are characteristically pigmented (plate C: 7), but small immatures are often almost entirely white and easily confused with the former species. Adults reach a body length of 5.0-6.5 mm and are found in greatest abundance just after budburst; immatures 2.8-3.3 mm long are also numerous then. *Pityohyphantes rubrofasciata* (plate C: 8) is often abundant in forests below 1300 m in the Oregon Coast and Cascade Ranges, where it largely replaces *P. brachygynus.*

5B Abdomen not distinctly higher than broad, at most circular in cross section . . . 6

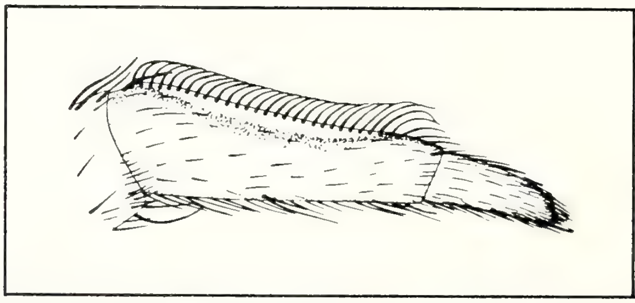


Figure 6—Hind leg of *Hyptiotes* with specialized row of setae on the metatarsus, termed the calamistrum.

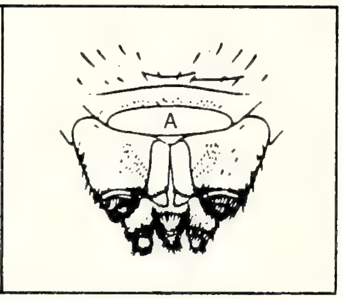


Figure 7—Spinnerets and cribellum (A) of *Hyptiotes.*

6A Metatarsus IV with a calamistrum (a comblike row of strong bristles along the margin; figs. 6, 8) and with a cribellum (a broad sclerotized plate) in front of the spinnerets (fig. 7); abdomen usually densely hairy 7

6B Metatarsus IV without calamistrum; cribellum absent 10

7A Eyes all light colored; tarsi with a single dorsal row of trichobothria (long sensory hairs perpendicular to the axis of the leg; fig. 8); local species have a red-brown cephalothorax, gray and orange-patterned abdomen, and robust chelicerae . . . . Amaurobiidae

Although not collected at Iron Mountain, *Callobius* (plate A: 6) and related genera are abundant in the region and may be encountered in trees. *Callobius* is commonly found on trunks and in epiphytic moss in more mesic forests in the Pacific Northwest. It is recognized by the double calamistrum and prominent trichobothria on both metatarsi and tarsi. A monograph by Leech (1972) treats all species of the Pacific Northwest; adult genitalia are necessary for identifying species and separating *Callobius* from *Amaurobius*. As adults, many of our species of amaurobiids are large, formidable predators (ca. 15-20 mm long).

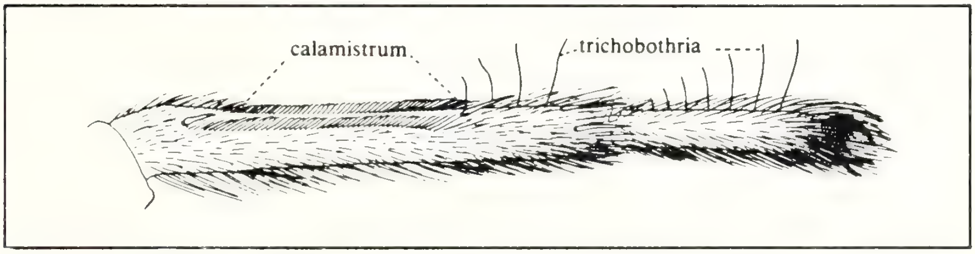


Figure 8—Hind tarsus of *Callobius*, showing the apparently double calamistrum and trichobothria.

7B Eyes all dark or heterogeneous (that is, some light and some dark) 8

8A Eyes heterogeneous, only anterior medians dark; anterior row of eyes nearly straight; small and hairy body (Dictynidae) 9

8B Eyes all dark, both rows strongly recurved, posterior lateral eyes pointing laterally (fig. 9); carapace angular, as wide medially as long; abdomen with 2-8 lateral tubercules; metatarsus IV depressed and concave above; variable in coloration, ranging from predominantly yellow to entirely dark brown, often with contrasting light-colored designs . . . . *Hyptiotes gertschi*

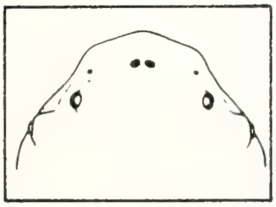


Figure 9—Eye placement of *Hyptiotes*.

This is the only species of uloborid likely in El Dorado. *Uloborus diversus* and *H. tehama* may be present but have not yet been collected (see revision by Muma and Gertsch 1964). *Uloborus* is distinguished by a vertical clypeus (equal in height to one diameter of anterior median eye) and a dense brush of hairs on tibia I of larger stages; *H. tehama*, as variably colored as *H. gertschi*, is distinguished only by the broad, spatular tip of the median genital apophysis.

Adult female *H. gertschi* (plate A: 1-2) are found year-round and average 3-4 mm in body length; males are much smaller, about 2 mm at maturity, and peak in abundance in August and September. *Hyptiotes* generally feign death when beaten from branches; their irregular profile and cryptic coloration make detection on a beating sheet difficult.

9A White-to-yellow stripe on carapace at base of legs; posterior margin of cheliceral fang furrow with 2-3 teeth (fig. 10) . . . . *Mallos pallidus*

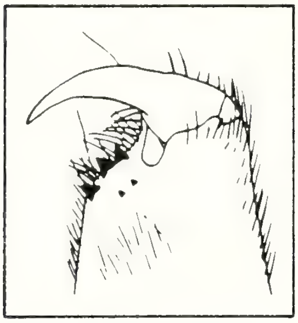


Figure 10—Left chelicera of *Drassodes,* showing distinct teeth on the posterior margin of the fang furrow.

Though not a monotypic genus, *M. pallidus* (plate A: 5) is the only species likely to key here. Females average 3.5 mm long, males 3 mm. This species, uncommon at our research areas, is widespread but always in low abundance in arboreal samples throughout the montane west coast.

9B Carapace without contrasting marginal stripe; posterior margin of cheliceral fang furrow with a single tooth . . . . *Dictyna* spp.

Several dozen species of this diverse genus are found in this region (Chamberlin and Gertsch 1958); the habits of nearly all species are unknown. Color pattern on the abdomen varies considerably between sexes and within a population. Species are identified by adult genitalia. *Dictyna peragrata* (plate A: 4) has been collected at El Dorado: white or dusky abdomen (never yellowed), carapace with anteriorly blackened margin, sternum without black midline, abdomen with basomedial spot and apical chevrons (missing in small immatures), carapace light red-brown to chestnut. Adults of both sexes are found throughout the year, females 2.5 mm, males 2.0 mm long. Though abundant in *Abies* forests in the Pacific Northwest, this species is uncommon in California.

This species group, which includes *D. peragrata,* seems primarily arboreal (especially on *Picea* and *Abies* in moist sites) throughout the Pacific Northwest; most other species in the diverse genus are inhabitants of shrubs or low forbs. *Dictyna francisca* inhabits the coast from San Diego to northern California; *D. peragrata* in the major mountain axes from northern Alaska to central California and Montana; *D. chitina* in the Alaska panhandle; and *D. uintana* (plate A: 3) in the montane Great Basin and Rocky Mountains from central Idaho south to Arizona. These largely allopatric species are distinguished by minute genitalic differences (see Chamberlin and Gertsch 1958). *Mallos trivittatus,* also keying out in 9B, can be distinguished from *Dictyna* by two teeth on the promargin of the chelicerae (one in *Dictyna)* and by the much larger adult (4-8 mm long).

10A Tibia and metatarsus I and II with a prolateral row of long spines, each long spine separated by a set of smaller spines that are apically curved and increase in length distally (fig. 11) . . . . Mimetidae

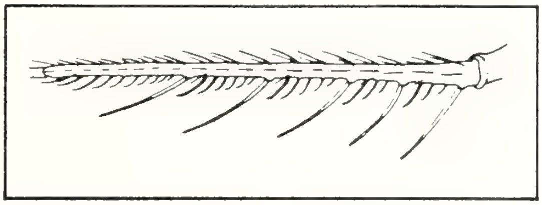


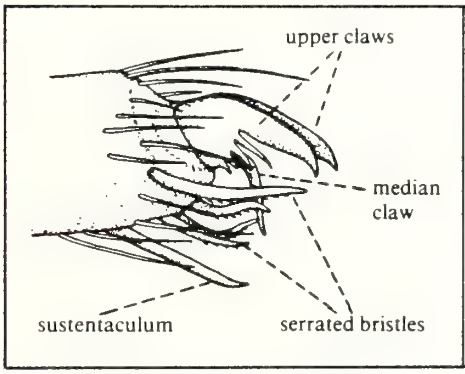
Figure 11—First metatarsus of *Mimetus* showing pattern of spination.

The genus *Mimetus* (plate D: 8), not recently revised, reportedly feeds primarily on other spiders. An araneid species, *Metellina mimetoides* (plate D: 7), may be confused in this couplet, although the spine pattern lacks the intervening spines; this species also has two small tubercles on the summit of the abdomen, easily visible in profile. Both genera were rarely collected in our studies.

10B Front tarsi without this unique spine arrangement 11

11A Tarsi with two claws and a terminal tuft of conspicuous hair (fig. 13); elongate spiders with relatively short, thick legs; abdomen roughly cylindrical 12

11B Tarsi with three claws but no tuft of hair (fig. 12; the tuft of 11A is easier to see than third claw of 11B); legs often thin and long; abdomen often rotund and distinctly taller or distinctly wider than carapace (except for Agelenidae, couplet 14A) 14



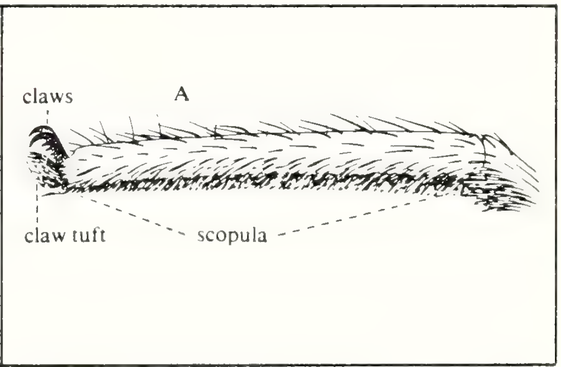


Figure 12—Tip of hind tarsus of *Araneus* showing the bristles and three claws.

Figure 13—Tarsus of *Tibellus* showing only two claws and a dense tuft of scales.

12A Anterior spinnerets truncate, cylindrical, longer and more heavily sclerotized than the posterior, separated basally by width of a single spinneret (fig. 14); eyes heterogeneous, only anterior medians dark, posterior medians often oblique; basal segment of pedipalpi with oblique depression on ventral face . . . . . Gnaphosidae

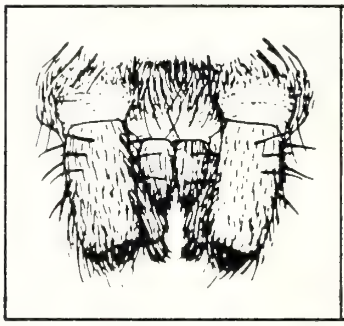


Figure 14—The truncate cylindric spinnerets of the Gnaphosidae.

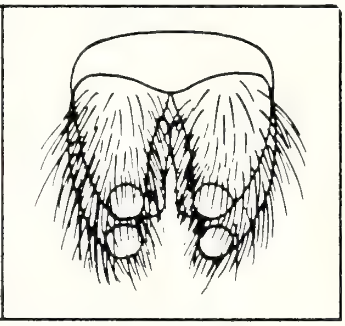


Figure 15—The conical spinnerets of the Clubionidae.

The only genus we have consistently encountered in Pacific conifers is *Sergiolus (=Poecilochroa),* recognized in all but its most immature stages by a dark gray-black body with a medial set of transverse white bars (plate A: 8). *Sergiolus montanus* is not abundant in arboreal samples. Adults (6-9 mm long) are most numerous in July, but are seldom beaten from trees; small immatures (2 mm long) are the stage usually collected near budburst. *Sergiolus columbianus* may also be encountered arboreally; it usually has a largely white abdominal venter (as a basal, posteriorly pointing triangle) and dark femora.

Many other species of gnaphosids are found on the forest floor and in low vegetation. The closely related genera *Herpyllus* (reported by Dahlsten et al. 1978 from Iron Mountain) and *Scotophaeus (S. blackwalli,* cited in Platnick and Shadab 1977 as occasionally arboreal—plate A: 7) have notched trochanters. *Zelotes,* also reported by Dahlsten et al. (1978), may be distinguished by the dense comb of setae—used for preening—on the apex of metatarsi III and IV. *Orodrassus canadensis* (uniformly light gray), reported by Platnick and Shadab (1978) as living arboreally, may be distinguished by the straight transverse posterior eye row; the four eyes are equidistant, with the posteromedial ones small and circular. *Nodocion voluntarius (=N. florissantinus*), a uniformly light-tan species, may be distinguished by the strong carina along the promargin of the chelicerae (instead of separate teeth like the preceding genera) and has been captured arboreally. All of these species should be expected in low abundance in Pacific Northwest conifers, but all are primarily ground dwellers.

12B Anterior spinnerets conical with pointed apices, bases nearly contiguous and as sclerotized as posterior ones (fig. 15); eyes homogeneous 13

13A Spiracle halfway between spinnerets and epigastric furrow (fig. 16; plate B: 3) (difficult to see on live or frozen specimens); tarsal tuft of prominent lamelliform hairs; carapace with faint but definite allatal stripes; abdomen with pink to lavender hue or whitish with indefinite pattern of gray spots . . . . *Anyphaena* spp.

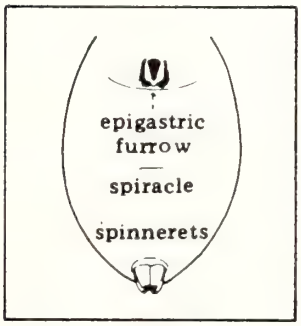


Figure 16—The venter of *Anyphaena* indicating the forward placement of the spiracle.

Four species of *Anyphaena* occur in this region: two are distinctively maculated species, one has a variable color pattern, and one has not been collected but is cited in the literature. A more southerly species, *Aysha incursa,* collected from oak in California, is distinguished by the spiracle one quarter of the distance from the epigastric furrow to the spinnerets.

Anyphaena aperta (plate B: 1), primarily a species of the coastal rain forests, may be distinguished by a single pair of ventral spines on metatarsi I and II. *Anyphaena gibboides* from the Great Basin, *A. californica* primarily from the coastal mountasins, and the widespread *A. pacifica* are not readily distinguishable in all stages; Platnick (1974) should be consulted for genital details.

The only species encountered in the Iron Mountain area is *A. pacifica;* it is variable in color pattern, the abdomen ranging from uniform tan to pink (plate B: 2) with numerous scattered maculations (contiguous posteromedially, plate B: 4). This species is consistently present and abundant at Iron Mountain, though seldom exceeding 10-percent relative abundance from arboreal samples throughout the Pacific Northwest. Adults average 5.0-5.5 mm in length; males are present in greatest numbers in June, females remain through summer. At budburst, immatures about 2 mm long are also abundant. Because members of this genus are reportedly nocturnal hunters, daytime collecting may underestimate their actual abundance if they refuge during the day close to the bole.

13B Spiracle located in normal position just in front of spinnerets; tarsal tuft simple . . . . Clubionidae

The Clubionidae have not been revised recently (except those in British Columbia by Dondale and Redner, 1982; this volume is very useful for most specimens from the Pacific States) and most genera are taxonomically confused. Three genera have consistently been collected in the Pacific States. *Trachelas* (Platnick and Shadab 1974a, b) has a dark red-brown carapace and sternum with a light tan to yellow abdomen; *T. pacificus* and *T. californicus,* distinguished most easily by genitalia, have occasionally been beaten from trees in the coastal rain forests of northern California and Oregon.

Occasional *Cheiracanthium* (two species: *C. inclusum* and *C. mildei)* have been collected arboreally. These yellow-tan spiders are more frequent on shrubs; they are distinguished from other clubionids by the absence of a blackened thoracic groove on the carapace. *Clubiona* (plate B: 6) is abundant on deciduous trees and shrubs in mesic habitats, not infrequently straying to conifers in the same locality. Species of *Clubiona* are entirely yellow-tan with differing patterns of red stippling on the abdomen, most frequently a longitudinal cardiac stripe with or without apical chevrons. Reference to adult genitalia of some of these species is in Edwards (1958).

14A Tarsi with a dorsal row of trichobothria, which usually increase in length distally (fig. 17); posterior spinnerets longer than anterior; distal segment of anterior spinnerets conical . . . . Agelenidae

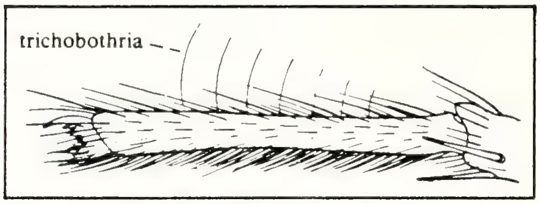


Figure 17—Tarsus showing a row of trichobothria.

This abundant and diverse ground-dwelling family is collected only occasionally from trees in the Pacific States. A representative of one abundant ground-dwelling genus is shown in plate B: 7. Roth and Brame (1972) should be consulted for adult specimens. The predominantly arboreal and rare genera *Dirksia (D. cinctipes,* plate B: 5) and *Ethobuella (E. tuonops)* inhabit coastal rain forests from British Columbia to Oregon. *Ethobuella* has four pairs of ventral spines on tibia I; other genera of agelenids have three or fewer. *Hololena* and *Novalena* are also found arboreally; both genera have strongly procurved eye rows, which result in a 2-4-2 design in frontal view. The distal segment of the posterior spinnerets of *Hololena* is two-thirds as long as the basal one; the distal segment is at least as long as the basal one in *Novalena.* Both genera currently need revision.

14B Tarsi without trichobothria 15

15A Height of clypeus less than or equal to height of median ocular area (fig. 19; region of face delimited by outer borders of the four median eyes) 24

15B Height of clypeus greater than height of median ocular area (fig. 18) 16

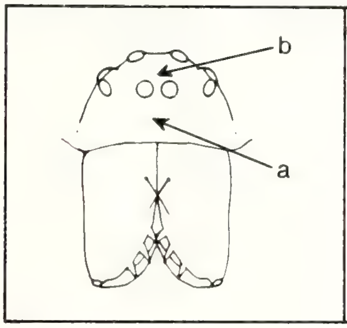


Figure 18—Face and chelicerae of *Pityohyphantes* (Linyphiidae) showing the clypeus (a) and the broad median ocular area (b).

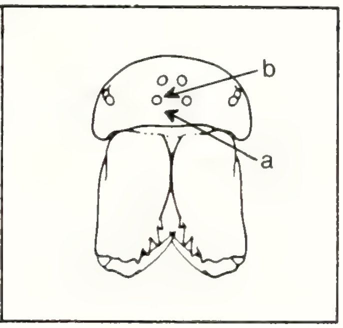


Figure 19—Face and chelicerae of *Araneus* (Araneidae) showing the clypeus (a) and narrow median ocular area (b).

16A Abdomen greatly extended beyond spinnerets; beige with silver reflections; posterior eye row procurved, posterior medians much further from each other than from posterior laterals; matures 5-10 mm long; infrequent; thought to invade webs of *Araneus* spp. and kill the resident spider (= *Rhomphaea lacerta)* (plate D: 3) . . . . *Argyrodes fictilium*

16B Abdomen not greatly elongated and vermiform 17

17A Abdomen with a dorsomedial brown-black triangle on reflective silver; eyes all light-colored; abdomen subtriangular, pointed posteriorly; leg IV longer than leg I . . . . *Euryopis formosa*

The widespread and common *E. formosa* (plate C: 2) can be distinguished from *E. coki,* a rarer species inhabiting the montane Great Basin, by the dark brown-black carapace and sternum and the almost entirely blackened abdominal venter. *Euryopis coki* has a yellow carapace and sternum with prominent silver stripes bordering the venter of the abdomen. The genus is reported to feed primarily on ants.

17B Abdomen not subtriangular; anterior median eyes dark 18

18A Abdomen largely pale brown to black 19

18B Abdomen white, at least on dorsum, with or without extensive superimposed markings (Linyphiidae, in part) 21

19A Posterior carapace distinctly overhung by abdomen; abdomen more than twice as high as carapace; clypeus of adults strongly concave and recessed under eye region (Theridiidae) 20

19B Cephalothorax and abdomen of roughly equal height; facial region of males often distorted . . . . Linyphiidae (Micryphantinae or Erigoninae)

This is a diverse group of minute spiders, rarely over 2 mm long as adults. Adult specimens should be sent to taxonomic specialists for species and even generic determinations. Several species have been collected arboreally at Iron Mountain; the most common is *Erigone.* Immature *Erigone* are gray with yellow legs; adults are black, often with yellow-orange legs (plate D: 4). Males have numerous prominent spines bordering the carapace. Another abundant arboreal genus that resembles *Erigone* females and immatures is *Spirembolus;* the male carapace is unarmed and the palps resemble a "plumbers helper," with a prominent spiral embolus at the apex. Some arboreal species of *Meioneta* will also key to this couplet, as will the abundant, gray *Ceraticelus atriceps.* Males of this latter species are distinguished by a large orange scutum on the abdomen; females have two pairs of orange ostial spots and an inconspicuous white herringbone on the posterior abdomen. The orange color appears in alcohol-preserved specimens; live spiders like the one illustrated are generally darker. Most micryphantine spiders are dark gray or black (plate D: 6). They are abundant and most diverse on the ground or in low vegetation.

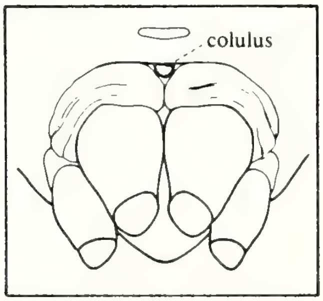


Figure 20—Spinnerets and colulus of *Xysticus.*

20A Abdominal venter with a colulus (a tiny wartlike appendage anteromedial to the spinnerets; fig. 20), at least half as long as the setae arising from it; abdomen with light band across the base of the dorsum; adults longer than 4.0 mm (plate C: 1); male abdomen with basal stridulating organ . . . . *Steatoda hesperos*

20B Abdominal venter with two setae where colulus would be; eye region of males extended dorsally to resemble the conning tower of a submarine; height of carapace (vertex to coxal bases) equals or exceeds carapace width; less than 4.5 mm . . . . *Dipoena* spp.

This genus has been revised by Levi (1953); two species are abundant in this region. *Dipoena nigra* (plate E: 5), adult length 1.5-4.5 mm, has an entirely black abdomen, a yellowish-brown carapace, and orange legs with apical black annulations. *Dipoena malkani* (adults 1.5-3.0 mm) has a bright orange carapace with a distinctive U-shaped depression on the top, orange legs, and a brown abdomen with a faint but distinctive pattern of orange ostial markings. Adults of both species are most frequent in June and July. Species of this genus are reported to be ant predators.

21A Legs greenish-yellow and unspotted; all of venter black, with a longitudinal white stripe on either side of the ventral flank; femora I and II without dorsal and lateral spines; patella of male palp without a spur . . . . *Neriene litigiosa*

This spider spins the most conspicuous web a hiker in this region will encounter. Adults are 5-6 mm long (plate C: 5) and their dome-shaped webs, up to 30 cm deep and 100 cm wide, are scattered in lower branches of trees and tall shrubs. At budburst, they are pre-adult. This species is cited in Dahlsten (1978) as *Prolinyphia sierrensis.* Another abundant species of the herb layer in mature forests is *Frontinella communis;* immatures are occasionally beaten from conifers.

21B Legs with yellow or buff background; venter unpigmented or with a uniformly black, median longitudinal band (small spiders not keying out in couplet 5) . . 22

22A Abdomen shiny, cuticle colorless, venter not blackened; abdomen underlain by white spheres; carapace unmarked . . . . *Gnathantes ferosa*

Also keying out here are other genera of micryphantine Linyphiidae. Less abundant than *Gnathantes* (plate D: 2) are species of *Meioneta* and *Microlinyphia.* These spiders are all poorly studied; specimens keying out here should be sent to specialists for identification.

22B Abdomen with black pigmentation 23

23A Abdomen with black pigmentation along sides; dorsum with a conspicuous medial black band with parallel sides *(Lepthyphantes* spp.) or black chevrons *(Linyphantes* spp.) . . . . Linyphiidae

Neriene digna, 3.5-5.0 mm long, has a white abdominal dorsum with a variable pattern of brown pigmentation on the posterior half, similar to that of *Cyclosa.*

23B Abdomen white laterally .... *Meioneta, Bathyphantes,* or immature *Pityohyphantes*

A diverse assemblage of tiny linyphiid spiders, all unstudied, will key out here. Even small immature *Pityohyphantes* has a distinctive Y-mark on the carapace.

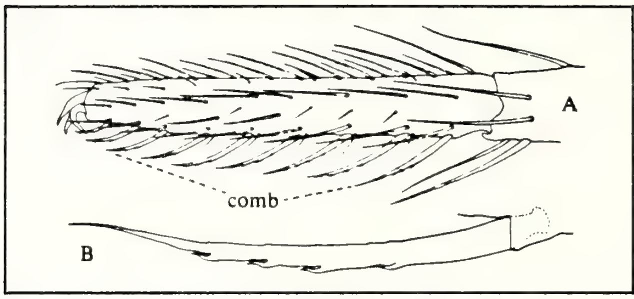


Figure 21—A: Entire hind tarsus of *Theridion* with position of tarsal comb indicated; B: A single serrated bristle of the comb.

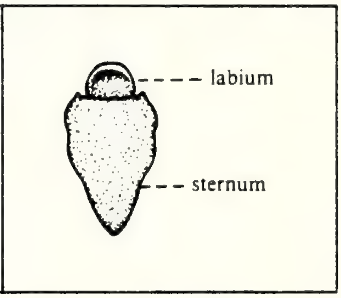


Figure 22—Sternum and labium of *Tetragnatha* showing the rebordered front margin of the labium.

24A Labium not rebordered (without thickened anterior edge); tibiae and metatarsi without prominent spines (some species with a slender dorsal spine on tibiae I and IV); tarsus IV with a ventral row of serrated bristles, the "tarsal comb" (difficult to see except under high power; fig. 21); eyes homogeneous or heterogeneous. (Immature *Tetragnatha* may seem to key out here, although it is not a theridiid; see couplet 25A. They may be distinguished by allatal stripes on the carapace, a silver abdominal dorsum and a median dark band flanked by silver commas on the abdominal venter.) .... Theridiidae

A. Abdomen creamy-white with five pairs of caudally converging black spots; carapace and sternum yellow-white; abdominal venter white with a median ventral black band (plate E: 3); an introduced spider frequenting deciduous shrubbery; adult length 4.0-6.0 mm (plate E: 4) .... *Enoplognatha ovata*

AA. Abdomen not white or with five pairs of small discrete black spots posterolaterally; venter of abdomen without parallel-sided black median band .... B

B. Carapace orange; abdomen orange-brown (plate F: 1-2), with white-bordered longitudinal stripe of brighter orange; submatures with a thin transverse white stripe; adults (1.5-3.5 mm) peak in abundance in June .... *Theridion differens*

BB. Carapace buff to yellow with a medial black Y or V C

C. Abdomen mostly white with faint pattern of paramedial interrupted stripes apparently not underlain by white deposits and hence translucent; abdomen with pair of black spots just posterior to the spinnerets; adults 3-4 mm long; abdomen not setose; adults peak in abundance during June and July .... *T. neomexicanum*

CC. Abdomen with black dorsal markings, usually as a black yoke on anteromedial portion; with setae on abdomen .... D

D. Anterior abdomen with anteriorly pointing black triangle with triangle width exceeding length; bases of abdominal setae surrounded by prominent blackened pustules; legs strongly annulated with black; venter of abdomen gray; adults (1.5 mm long) present throughout summer (plate E: 7) . . . . *T. crispulum (=T. intervallatum)*

DD. Anteromedial portion of abdomen without prominent black triangle; surface of abdomen not black pustulate . . . . E

E. Sternum with black midline and spots around border; black border on carapace; legs with distinct annulations, even in youngest spiders; adults (2-4 mm) peak in abundance during June and July (plate E: 8) . . . . *T. murarium*

EE. Sternum without black midline or border; leg annulations weak or absent . . . . F

F. Sternum without black markings; carapace lacking black margin; legs unmarked; adult 1.5-2.5 mm; adults peak in abundance during winter (plate F: 5-6) . . . . *T. sexpunctatum*

FF. Sternum lacking black midline but usually with black border; carapace with tenuous black margin; leg annulations often weak; adult 2.0-3.0 mm long; adults peak in abundance during June and July (plate F: 7-8) . . . . *T. lawrencei*

Other species that might be found include *Theridion melanurum,* an introduced spider frequenting disturbed habitats, which has a gray-black abdominal dorsum with a median scalloped parallel-sided white band; the dark venter has a white triangle between the spinnerets and the epigastric line. *Theridion montanum* is a sibling species of *T. lawrencei,* found in the Rocky Mountains and distinguished only by male genitalia. *Theridion aurantium (s. str.), T. agrifoliae,* and *T. californicum* (plate E: 6) are strictly coastal and encountered in large numbers on ericaceous shrubs; all three species are light-colored with yellow cephalothoraces, yellow to white unmarked legs, and predominantly white abdomens. All three species are variable in coloration; *T. aurantium* (plate F: 3-4) may have much of the abdominal dorsum obscured by paramedial stripes or a bull's-eye of black; genital characters (Levi 1951) are the only reliable species discriminators. The closely related *Thymoites (=Paidisca) pictipes* has been recorded from tree bark; it has an orange carapace and sternum and a uniformly gray to black abdomen.

24B Labium rebordered (fig. 22); tibiae and metatarsi with two or more well-developed spines; tarsus IV without row of serrated bristles; eyes homogeneous 25

25A Femora with trichobothria; epigastric furrow (fig. 23) between lung slits procurved; venter of abdomen with median black band; adults large with elongate legs I and II and long cylindric abdomen; carapace with dark allatal stripes; silvery integument dorsally and laterally on abdomen; venter of abdomen with a dark center band and silver commas on each side (Tetragnathidae) . . . . *Tetragnatha* spp.

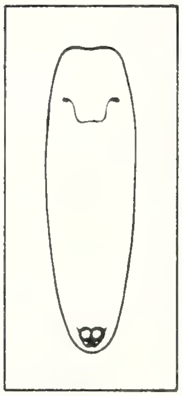


Figure 23—*Tetragnatha,* venter showing procurved apigastric furrow.

Adults of the endemic species of this genus usually inhabit foliage overhanging running water; immatures wander far from water. The two most common species in the region (Levi 1981) may be distinguished as follows: *T. laboriosa* (plate C: 4) with lateral eyes not contiguous, separated by more than their diameters, abdomen in side view nearly cylindrical, dorsum of abdomen silvery, adult length 4-9 mm; *T. versicolor* (plate C: 3) with lateral eyes nearly contiguous; abdomen in side view somewhat oval, anterior height 1.5-2.5 times height of carapace; dorsum of abdomen with variable darkened midline on silvery background, adult 4.5-13.5 mm. *T. versicolor* is one of the most frequently encountered arboreal spiders of the Pacific Northwest; *T. laboriosa* is primarily a species of open meadows and disturbed areas, infrequently collected in climax forests.

25B Femora without trichobothria; epigastric furrow straight; venter with or without median longitudinal band; chelicerae held vertically; without color patterns described above (Araneidae) 26

26A Little black on venter; abdomen white with eight posterolateral black spots arranged in two converging lines; carapace and legs bright yellow or orange; median ocular area as wide behind as in front with posterior eyes slightly larger than anterior medians . . . . *Araniella displicata*

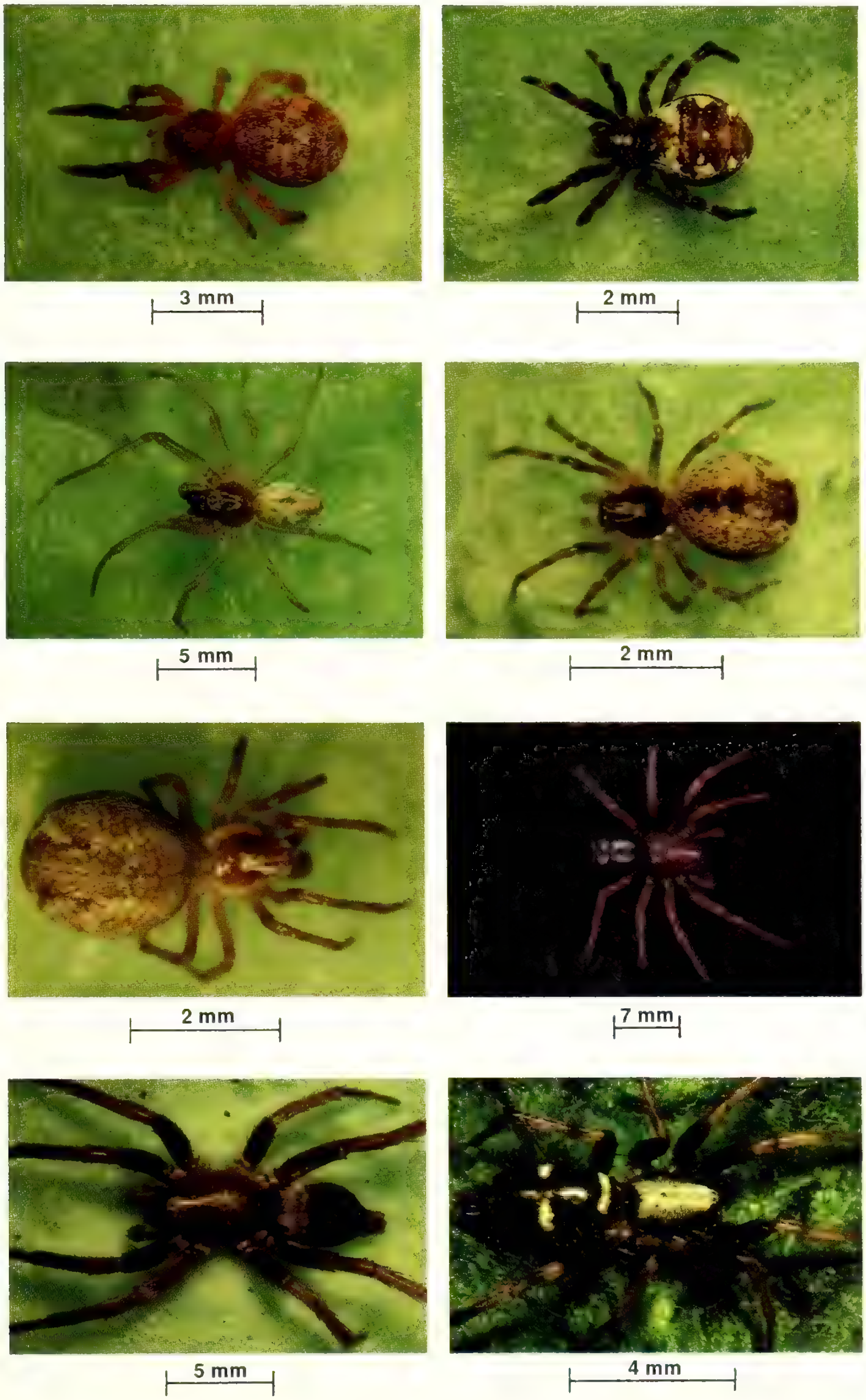
This distinctly colored spider (plate G: 4) is abundant and widespread. The abundant arboreal theridiid *Enoplognatha ovata* is similar (plate E: 4) but has not been collected in the central Sierra Nevada (Levi 1957). During colder months, larger *A. displicata* have additional dark red-orange smudges sublaterally on the abdomen (plate G: 3). Adult males (4-5 mm) are half the size of adult females (6-8 mm) and are usually encountered only in early spring; females may be found throughout summer. Immatures, present throughout the year, are most abundant in early fall.

26B Venter with prominent black pigmentation, or, if nearly light-colored throughout, at least with a median gray stripe contrastingly flanked by white 27

27A Two white comma-shaped maculations adjacent to black abdominal midventral line (plate H: 6) 29

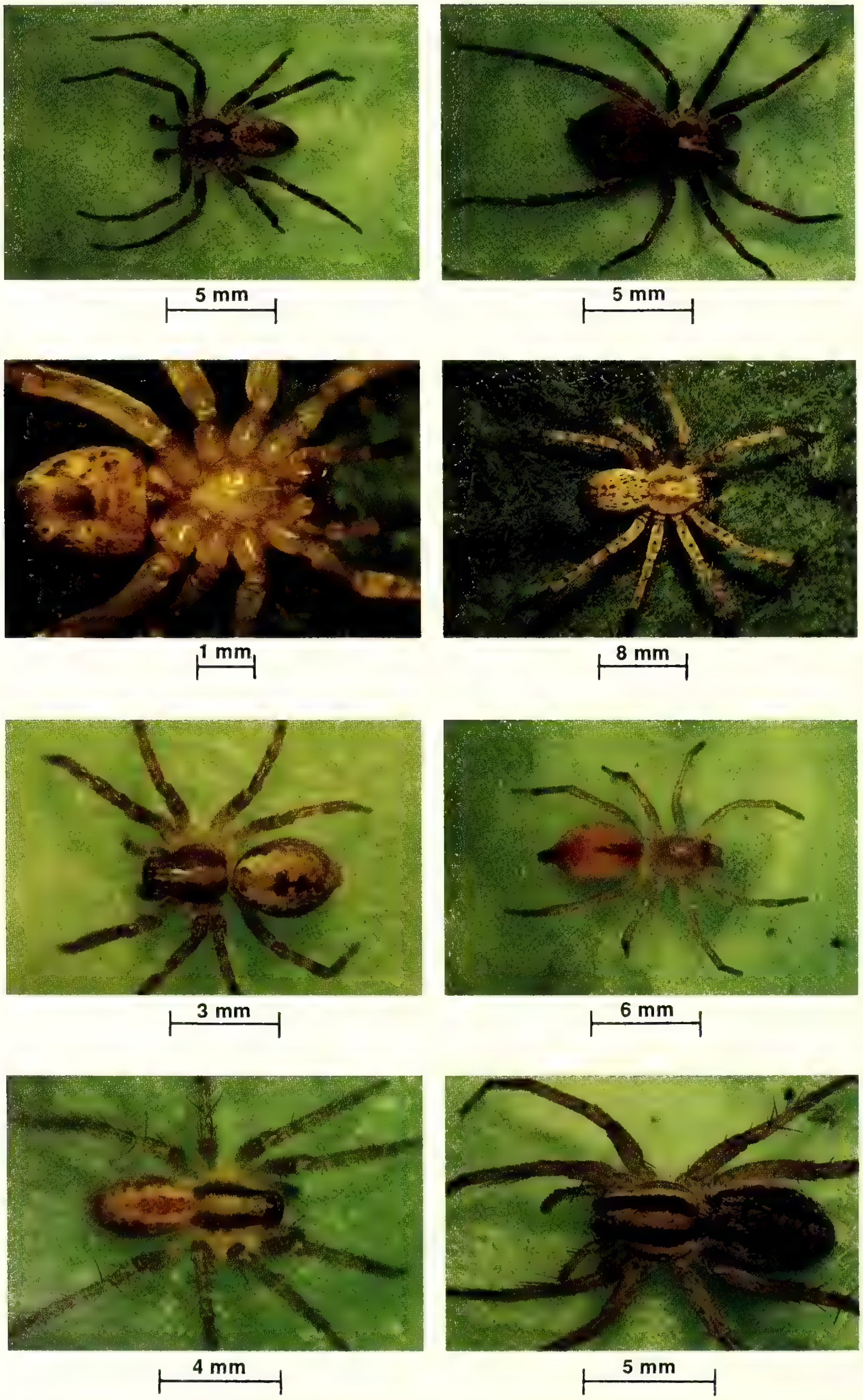
27B Abdominal venter not narrowly black or flanked by two white commas (plate H: 8) 28

Plate A



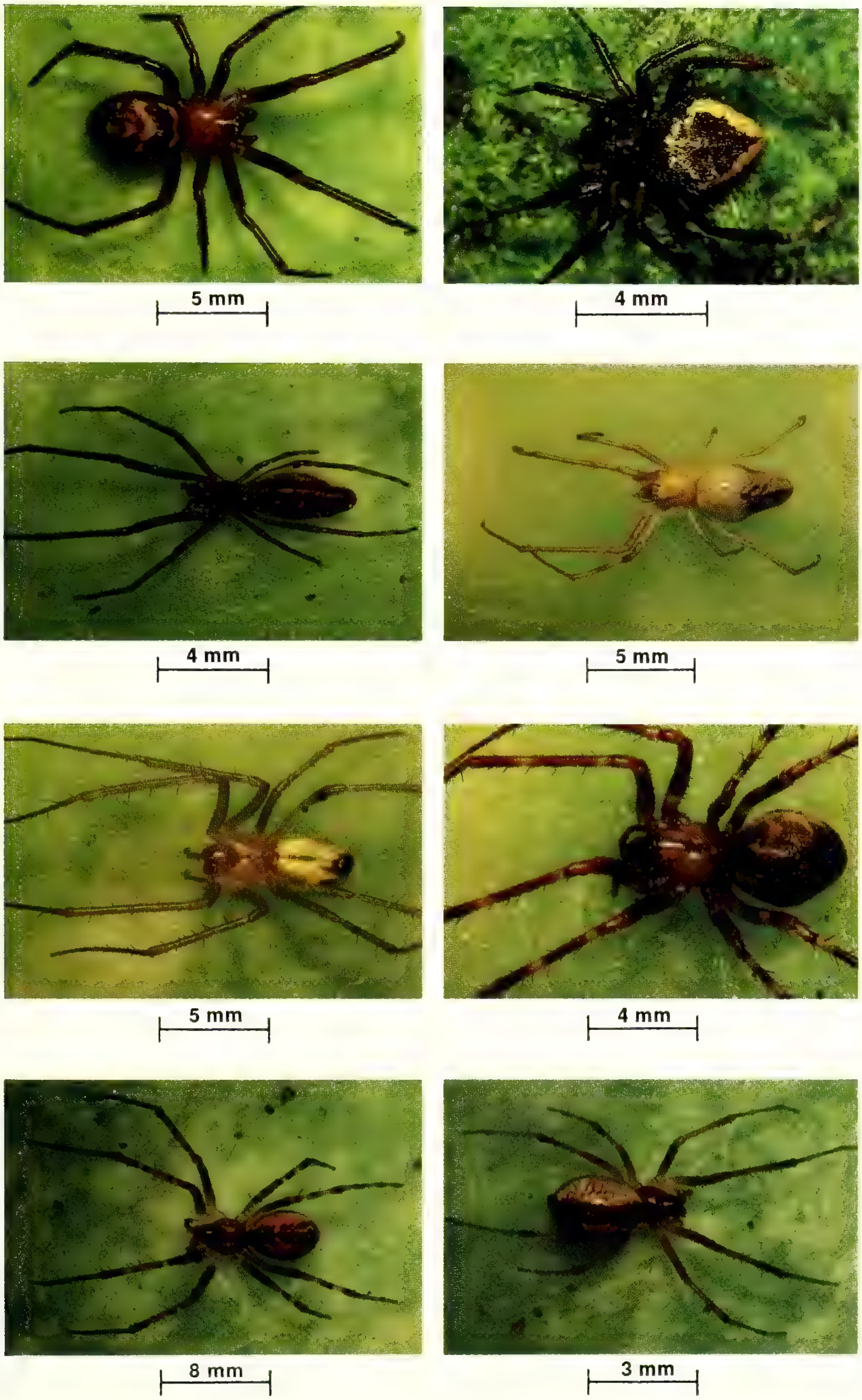
1—*Hyptiotes gertschi,* female; 2—*Hyptiotes gertschi,* subfemale; 3—*Dictyna uintana,* male; 4—*Dictyna peragrata,* female; 5—*Mallos pallidus,* female; 6—*Callobius severus,* female; 7—*Scotophaeus blackwalli,* female; 8—*Sergiolus montanus,* male.

Plate B



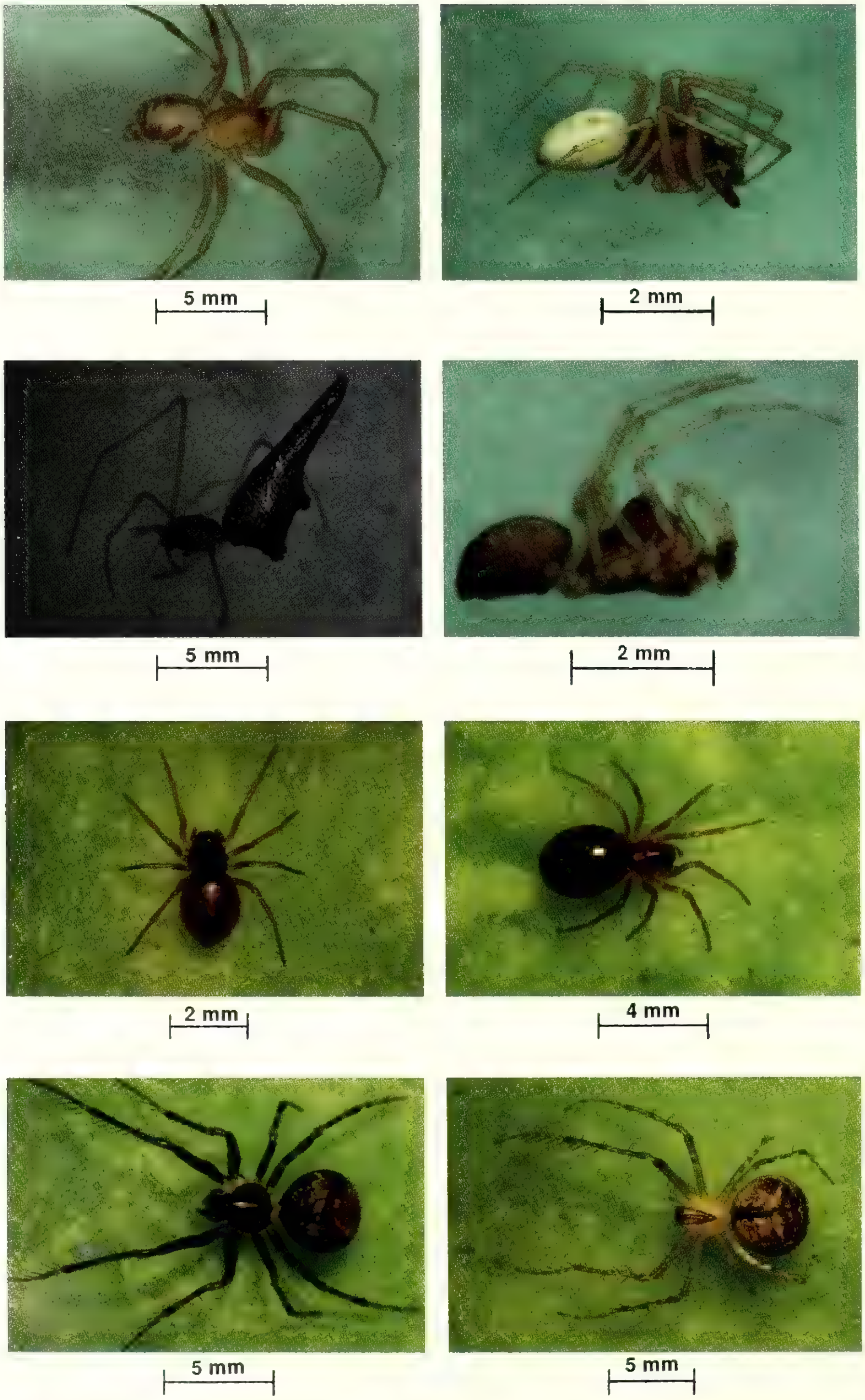
1—*Anyphaena aperta,* male; 2—*Anyphaena pacifica,* submale; 3—*Anyphaena pacifica,* female spiracular region; 4—*Anyphaena pacifica,* spotted female morph; 5—*Dirksia cinctipes,* female; 6—*Clubiona canadensis,* subfemale; 7—*Agelenopsis oregonensis,* immature; 8—*Pardosa* sp., immature.

Plate C



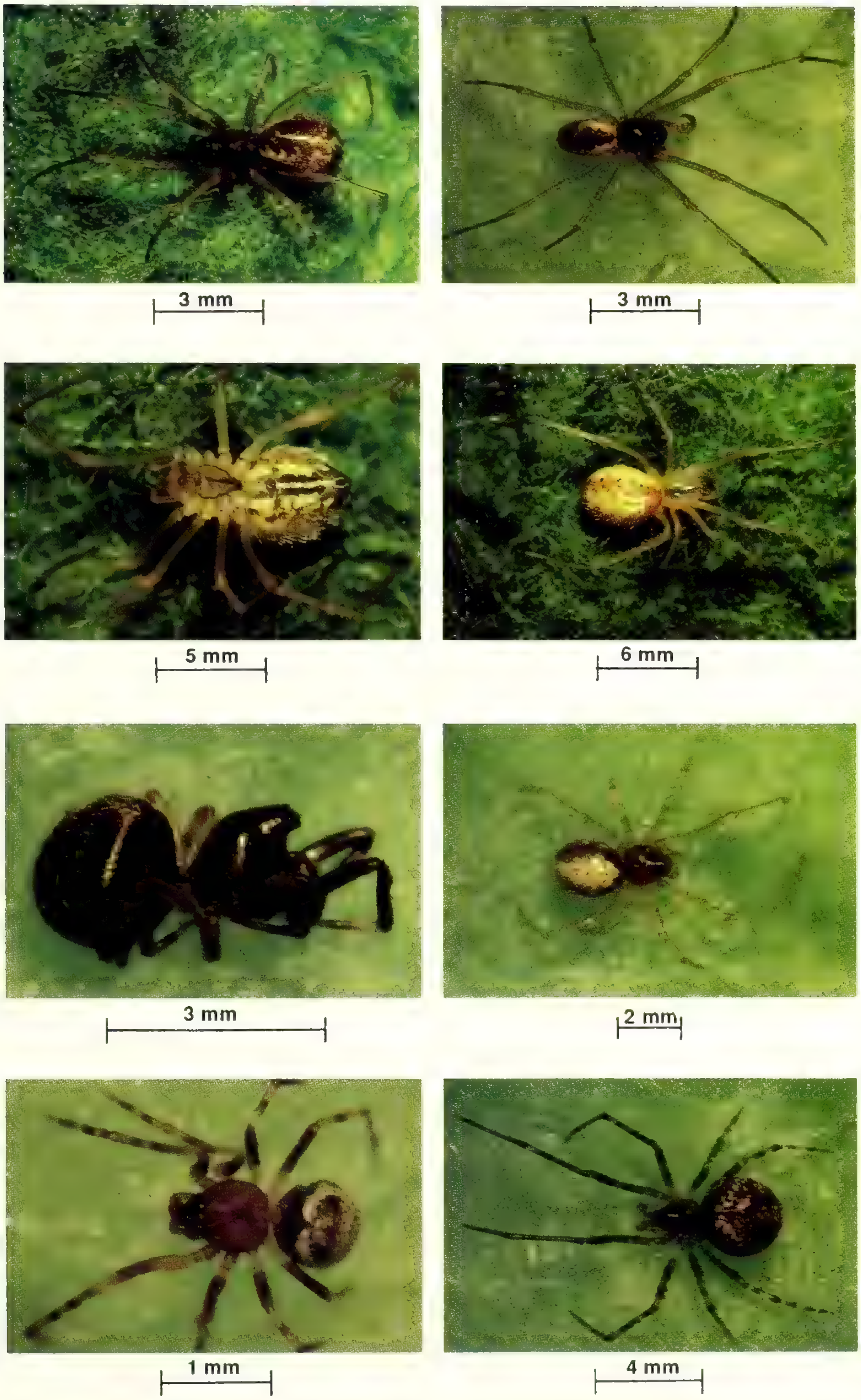
1—*Steatoda hesperos,* large immature; 2—*Euryopis formosa,* female; 3—*Tetragnatha versicolor,* subfemale; 4—*Tetragnatha laboriosa,* female; 5—*Neriene litigiosa,* female; 6—*Pimoa altioculata,* female; 7—*Pityohyphantes brachygynus,* subfemale; 8—*Pityohyphantes rubrofasciata,* subfemale.

Plate D



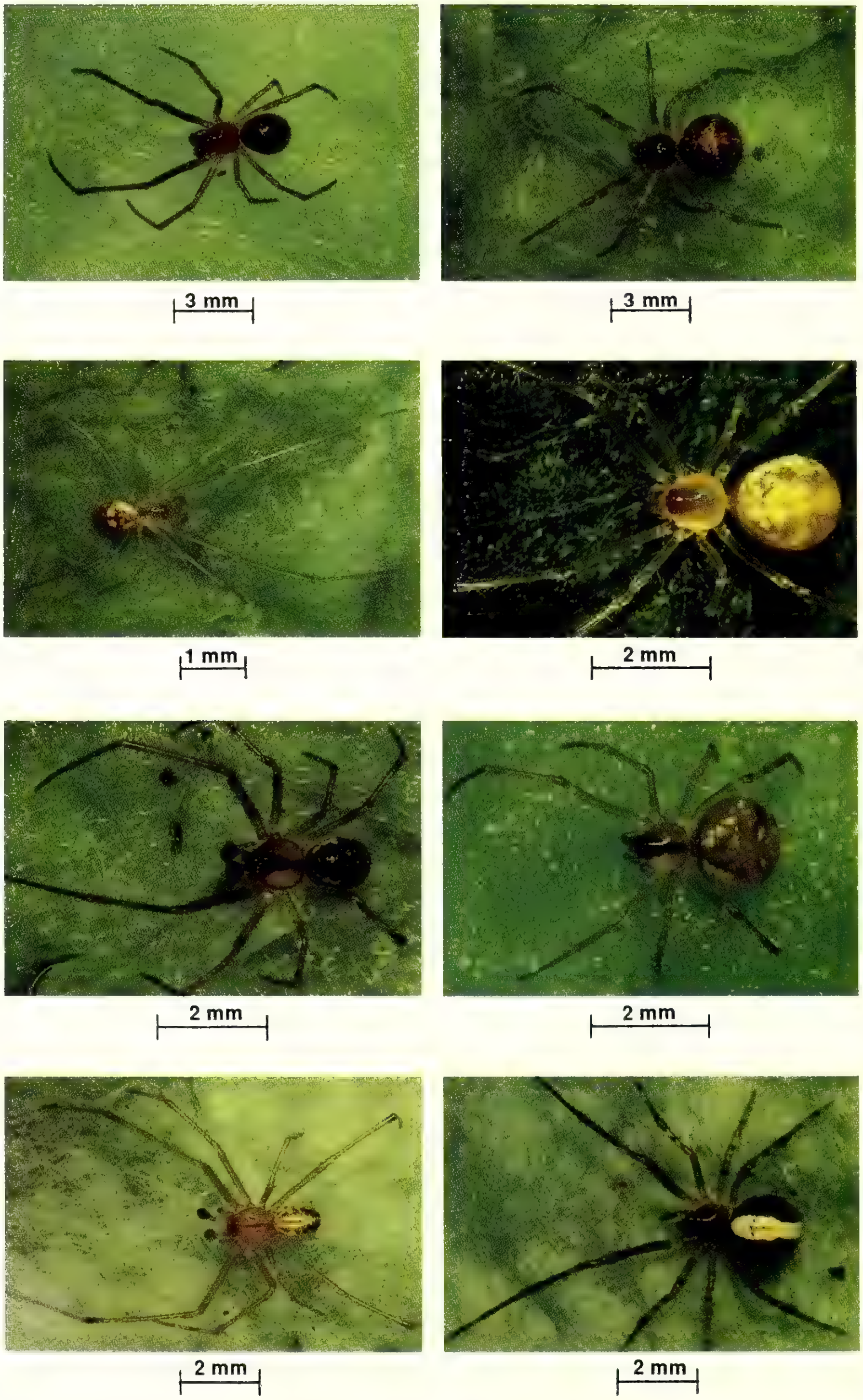
1—*Linyphantes* sp., female; 2—*Gnathantes ferosa,* male; 3—*Argyrodes fictilium,* subfemale; 4—*Erigone californica,* male; 5—*Ceraticelus atriceps,* female; 6—*Bathyphantes* sp., female; 7—*Metellina mimetoides,* female; 8—*Mimetus hesperus,* submale.

Plate E



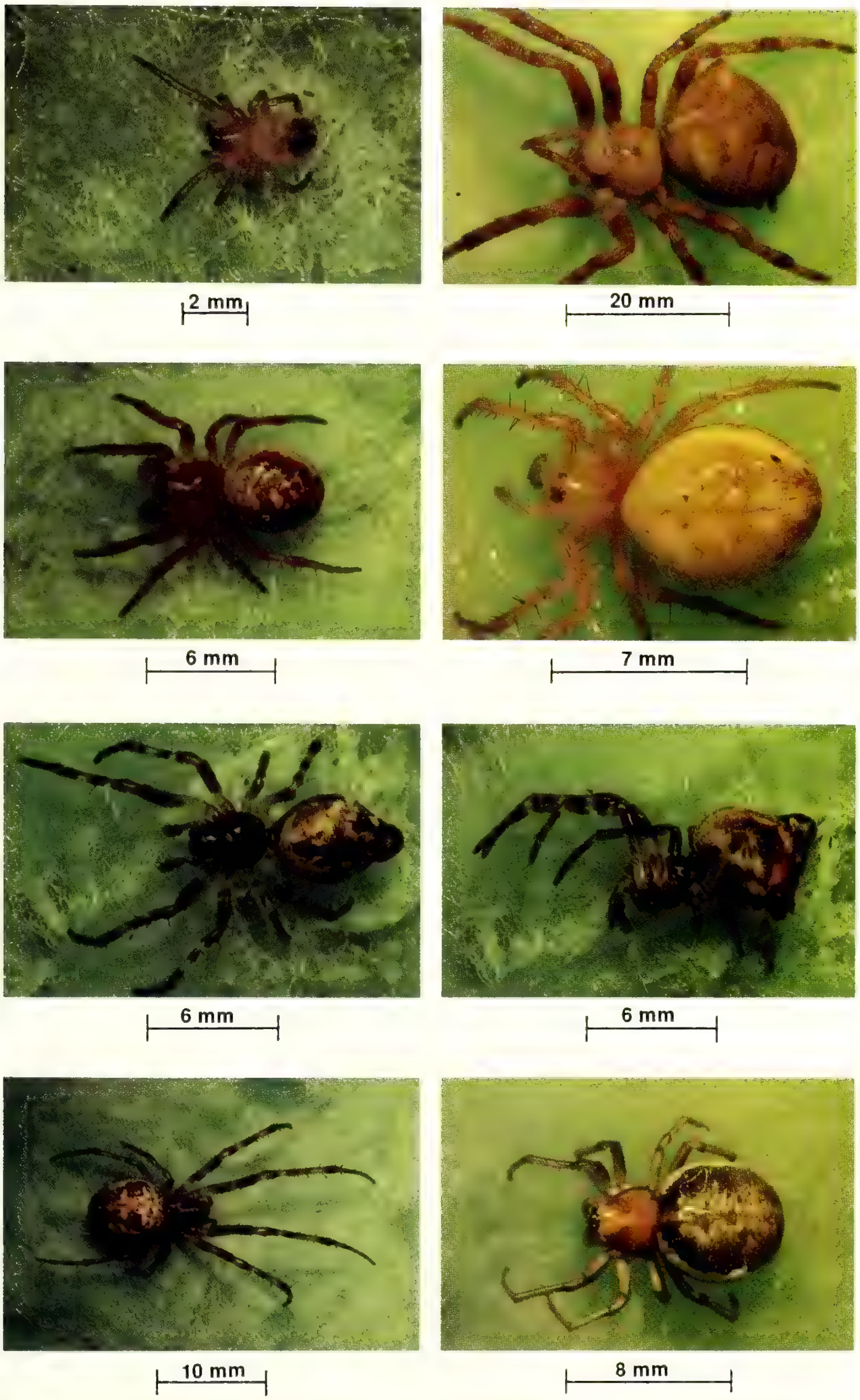
1—*Frontinella communis,* immature; 2—*Neriene digna,* submale; 3—*Enoplognatha ovata,* ventral view of female; 4—*Enoplognatha ovata,* female; 5—*Dipoena nigra,* female; 6—*Theridion californicum,* subfemale; 7—*Theridion crispulum,* male; 8—*Theridion murarium,* female.

Plate F



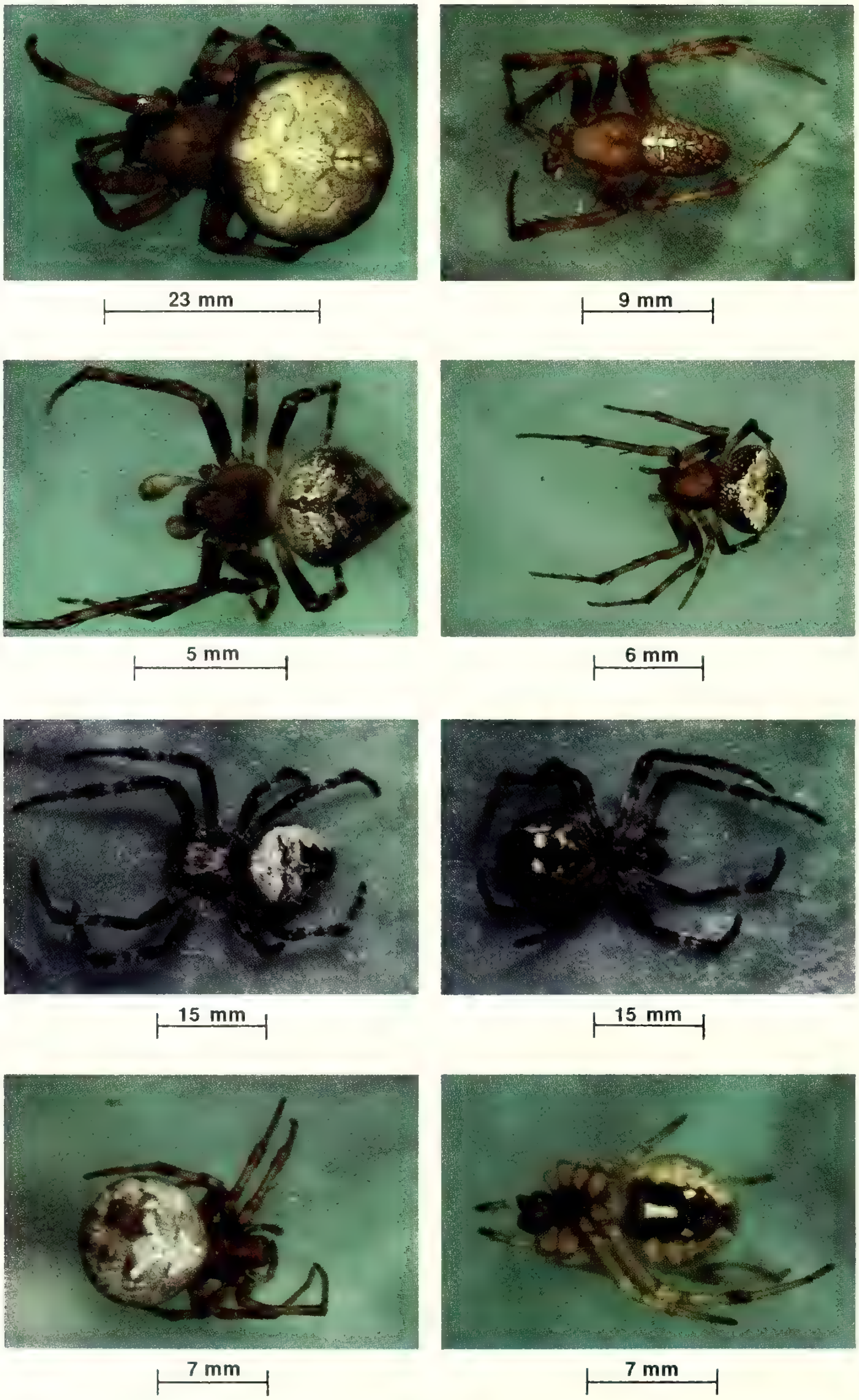
1—*Theridion differens,* male; 2—*Theridion differens,* female; 3—*Theridion aurantium,* male; 4—*Theridion aurantium,* female; 5—*Theridion sexpunctatum,* male; 6—*Theridion sexpunctatum,* female; 7—*Theridion lawrencei,* submale; 8—*Theridion lawrencei,* female.

Plate G



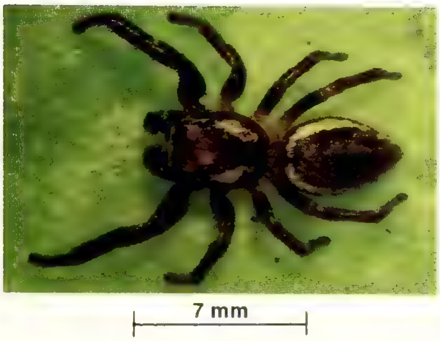
1—*Araneus gemmoides,* immature; 2—*Araneus gemma,* female; 3—*Araniella displicata,* subfemale in winter color; 4—*Araniella displicata,* female in summer color; 5—*Cyclosa conica,* female; 6—*Cyclosa conica,* female; 7—*Nuctenea patagiata,* female; 8—*Zygiella carpenteri,* female.

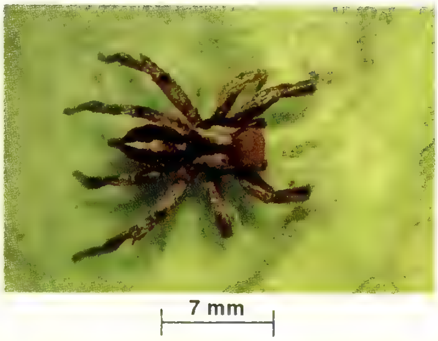
Plate H

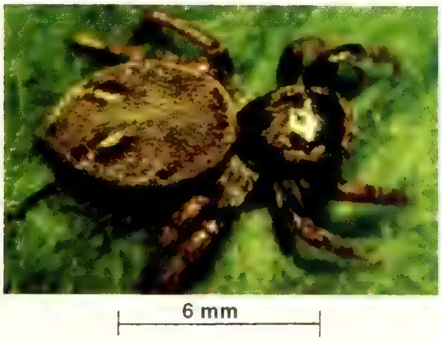


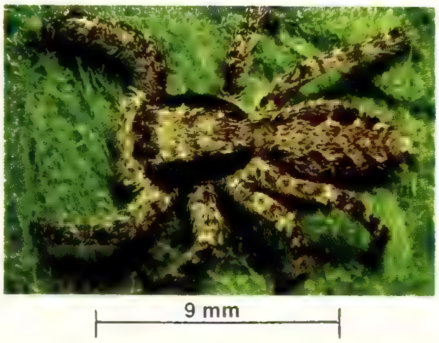
1—*Araneus marmoreus,* female; 2—*Araneus diadematus,* male; 3—*Eustala rosae,* submale; 4—*Araneus montereyensis,* female; 5—*Araneus saevus,* subfemale; 6—*Araneus saevus,* subfemale venter; 7—*Metepeira grandiosa,* female; 8—*Metepeira foxi,* female.

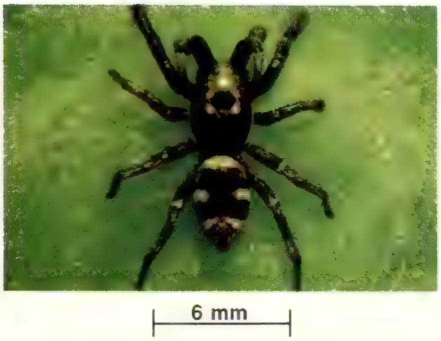
Plate I

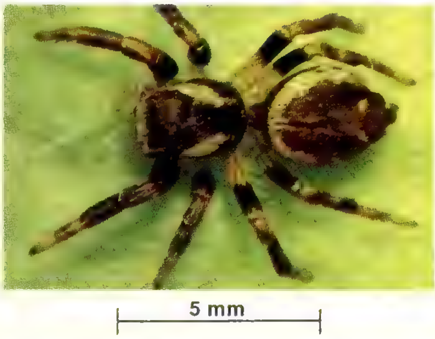


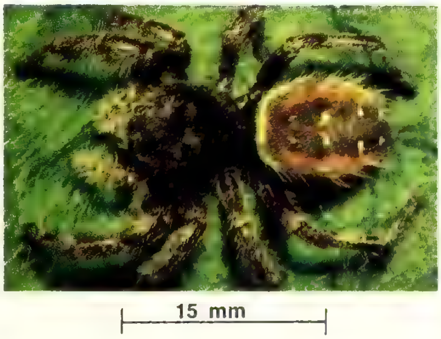


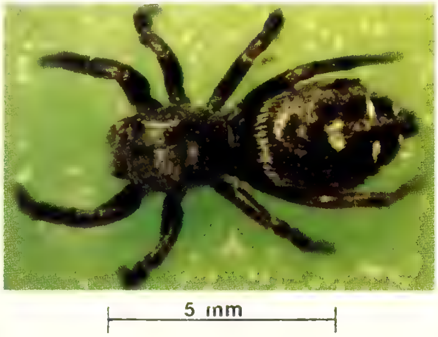






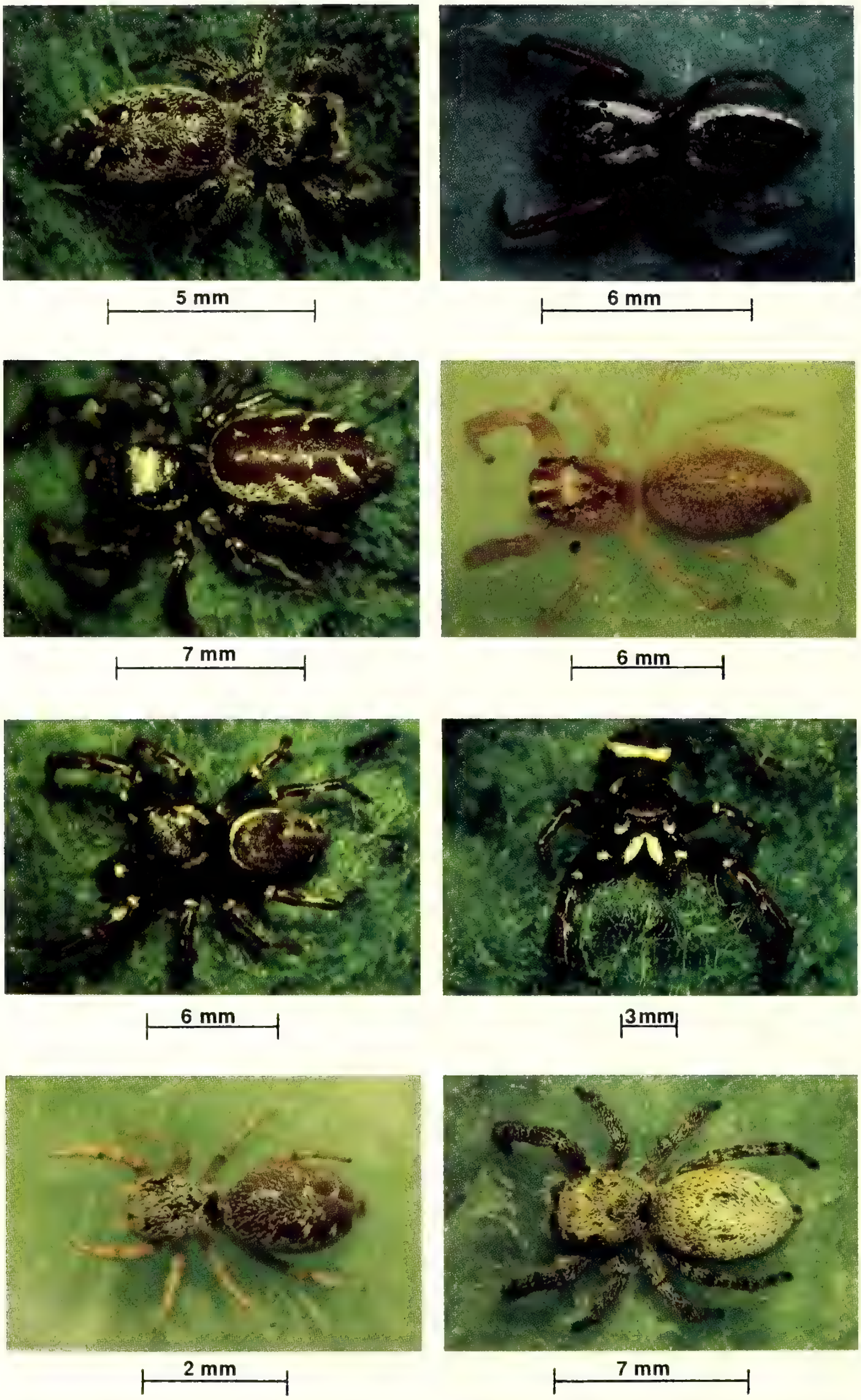






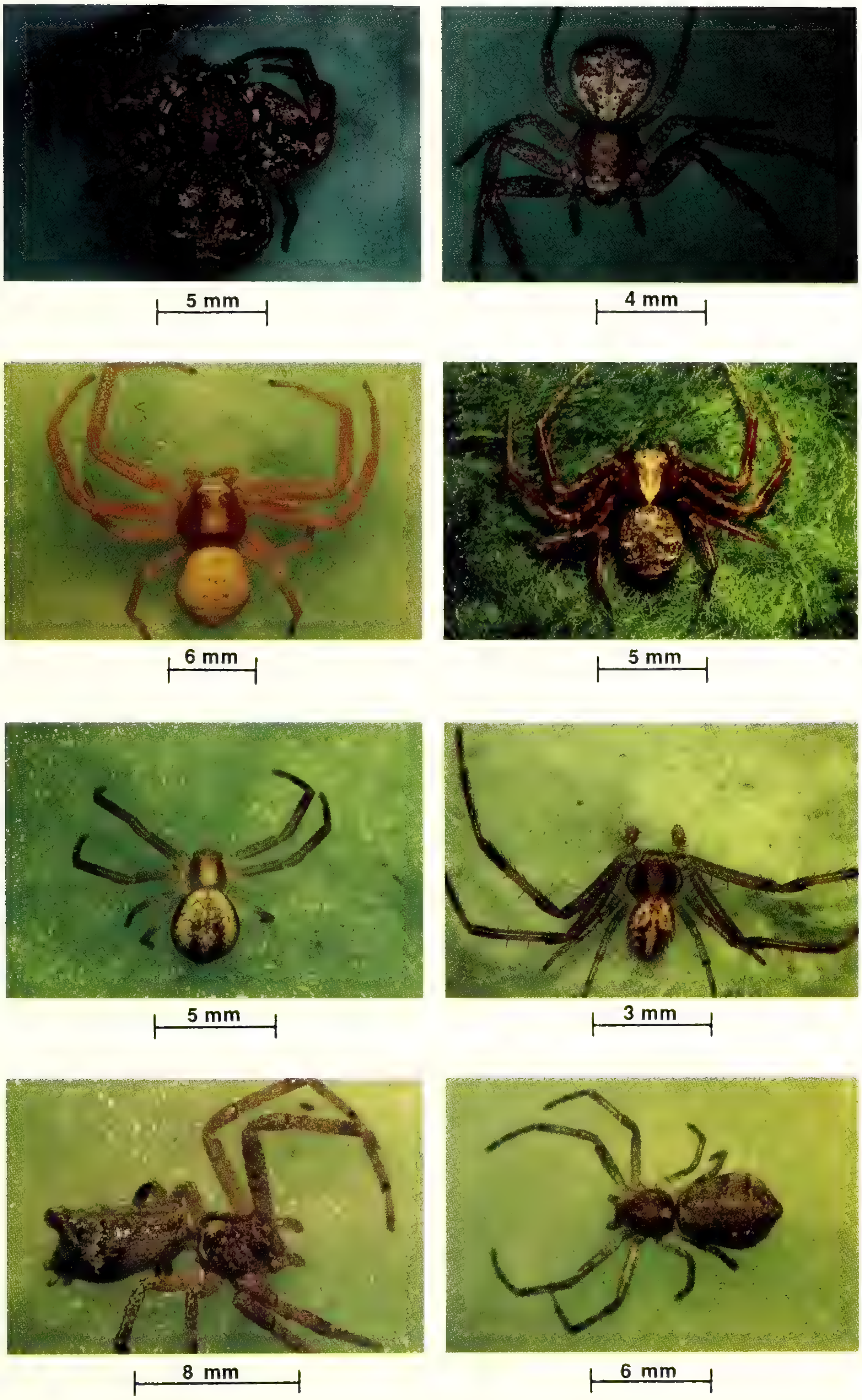
1—*Eris marginata,* male; 2—*Habronattus jucundus,* male; 3—*Evarcha hoyi,* female; 4—*Metacyrba californica,* female; 5—*Salticus scenicus,* male; 6—*Evarcha hoyi,* submale; 7—*Phidippus johnsoni,* female; 8—*Phidippus* sp., immature.

Plate J



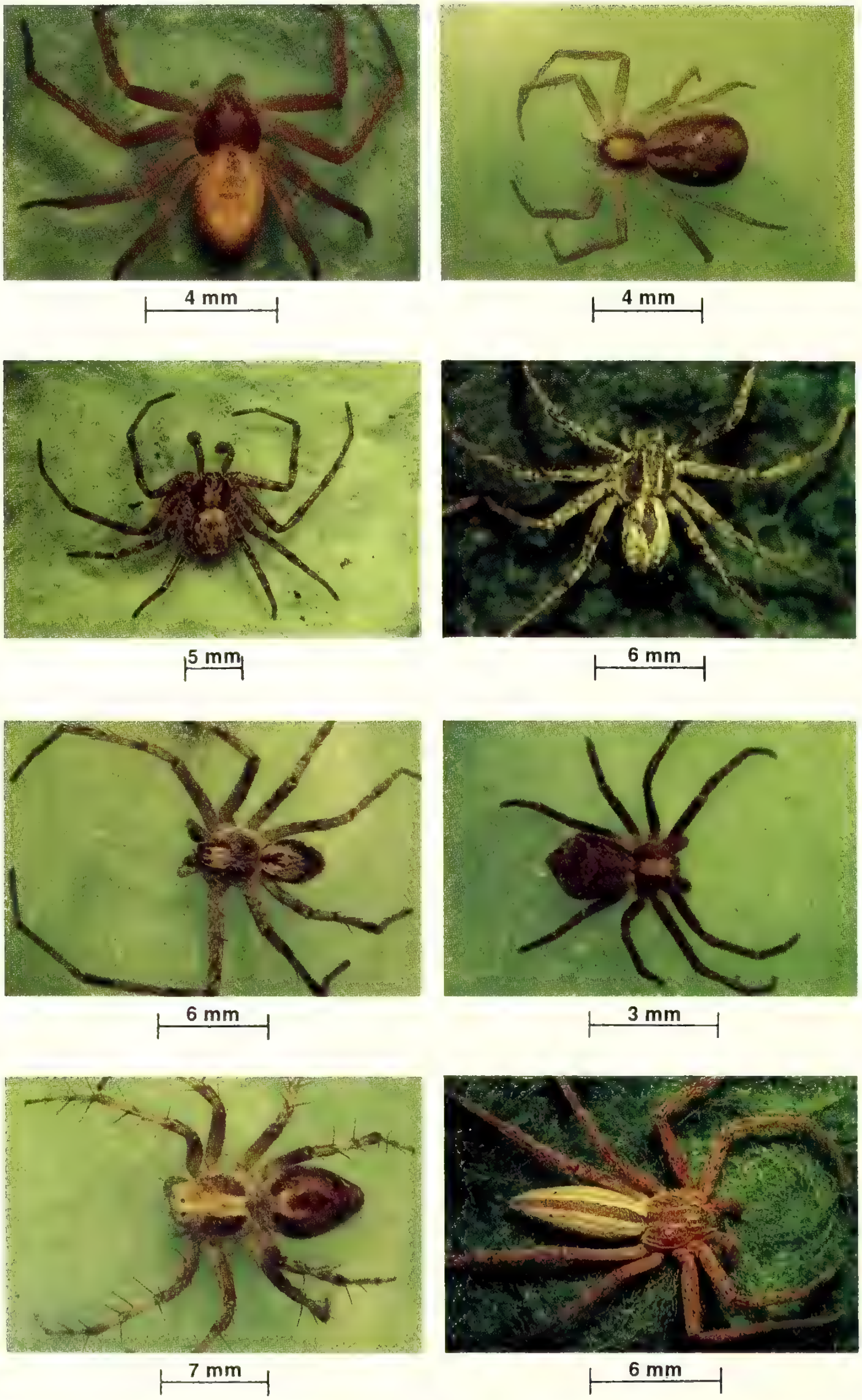
1—*Metaphidippus aeneolus,* subfemale; 2—*Metaphidippus albeolus,* male; 3—*Metaphidippus aeneolus,* worn female; 4—*Metaphidippus watonus,* female; 5—*Metaphidippus aeneolus,* male; 6—*Metaphidippus manni,* male facial view; 7—*Metaphidippus aeneolus,* immature; 8—*Metaphidippus* n. sp., female.

Plate K



1—*Coriarachne utahensis,* female; 2—*Xysticus gosiutus,* female; 3—*Misumena vatia,* subfemale; 4—*Xysticus locuples,* male: 5—*Misumena vatia,* submale; 6—*Misumenops celer,* male; 7—*Tmarus angulatus,* female; 8—*Tmarus angulatus,* immature.

Plate L



1—*Philodromus rufus,* female; 2—*Philodromus quercicola,* female; 3—*Philodromus spectabilis,* subfemale; 4—*Thanatus altimontis,* male; 5—*Apollophanes margareta,* male; 6—*Philodromus gertschi,* submale; 7—*Oxyopes scalaris,* female; 8—*Tibellus oblongus,* submale.

28A Abdomen strongly triangular, with subapical projection overhanging the posterior; venter of abdomen posteromesally white with submedial irregular blackenings; markings of abdominal dorsum variable, generally resembling a black deltoid leaf with petiole pointing anteriorly on a white background (laterally with numerous brown flecks); adults 4.5-7.5 mm long; infrequent in samples . . . . *Eustala* spp.

The introduced *E. anastera* (with only one caudal hump, dark brown carapace with prominent white cloak of hairs) is found throughout the region. *Eustala rosae* (plate H: 3) has three caudal humps and a yellow-brown carapace; it is widely distributed in the montane Pacific Northwest. Both species are nocturnal.

28B Abdomen smoothly oval, without basolateral or subapical projections; abdomen with a large foliar design characterized by rounded lobes; all legs of both sexes with length of tarsus plus the metatarsus greater than the length of the patella plus the tibia; abdominal venter with white midline flanked by a wide field of black . . . . *Metepeira* spp.

Two frequent species with black sterna are found throughout the region, usually in association with deciduous shrubby vegetation. *Metepeira foxi* (plate H: 8) is found primarily east of the Cascade-Sierra axis, and *M. grandiosa* (plate H: 7) lives primarily west of the mountain backbone; the only reliable method of separating the species uses genital characters (Levi 1974). *Metepeira gosoga, M. ventura, M. crassipes,* and *M. grinnelli* might stray into this area; all of these species have a longitudinal white band on the black sternum.

29A Prominent apical tubercle on abdomen (plate G: 6); abdomen cylindric, sides not strongly converging posteriorly, and white with a dissected black longitudinal design; youngest immatures with a trapezoidal abdominal maculation instead . . . . *Cyclosa conica*

This is a widespread species consistently encountered in arboreal samples throughout the Pacific States. Adults average 4-7 mm in length. All but minute immatures can be identified by the distorted abdomen and the abdominal markings (plate G: 5-6); the only other arboreal spider with a similarly tuberculate abdomen is the crab spider, *Tmarus angulatus* (plate K: 7).

29B Abdomen without prominent subapical tubercle 30

30A Thoracic groove (linear darkened depression on summit of carapace) apparent; abdomen highest at middle; irregular foliar design entire length of abdomen . . . . *Zygiella* spp.

Two native species, *Z. carpenteri* (plate G: 8) and *Z. dispar,* are found throughout the Pacific Northwest; two introduced species *Z. atrica* (rare) and *Z. x-notata* (abundant) also primarily inhabit deciduous trees in disturbed regions. Species can be reliably distinguished only by adult genitalia (Levi 1977). The orb-weavers are nocturnal.

30B Thoracic groove inconspicuous; abdomen highest subbasally, usually oval or triangular in outline 31

31A Carapace setose; abdomen not triangular, without basal lateral humps except in adult males; abdomen with posteriorly pointing black triangle flanked by brown; legs with black annulations; abundant winter spider, especially on dead conifer twigs or deciduous branches in deep shade (plate G: 7) . . . . *Nuctenea patagiata*

31B Carapace not setose; abdomen triangular, highest basally . . . . *Araneus* spp.

A. Width of abdomen between strong basolateral projections much greater than length; dorsum and sides of abdomen principally light yellow or tan, occasionally with black posteriorly pointing triangle on dorsum; chaparral shrub inhabitants seldom found in trees; adults 4-6 mm long, active during winter (plate H: 4) . . . *A. montereyensis, A. bispinosus, or A. mariposa*

AA. Abdomen longer than wide; adults more than 10 mm long . . . . B

B. Abdomen brown or black and mottled; large lateral humps; legs dark brown, indistinctly banded (plate H: 5) . . . . *A. saevus, A. andrewsi, or A. nordmanni*

BB. Abdomen not entirely brown to black C

C. Abdomen with black and white contrasting patterns; carapace brown (plate H: 1) . . . . *A. marmoreus*

CC. Abdomen orange with brown foliar markings; carapace orange (plates G: 1-2, H: 2) . . . . *A. diadematus, A. gemmoides, or A. gemma*

Coloration of the species within each group varies; species determinations should be made by referring to the genital diagrams in Levi (1971, 1973). The most common and widespread species encountered in conifers are in the *A. gemma* group. The introduced *A. diadematus* is widespread in native forests and can be distinguished by the white crucifix on the base of the abdomen; the other two species are difficult to distinguish. Larger *Araneus* take 2 years to mature so that two size-classes are normally encountered (4.5-5.5 mm and 2.5 mm at budburst).

Key to the Jumping Spiders (Salticidae)

1A Gray with white stripes on abdomen: basal stripes continuous, three other pairs of stripes interrupted along middorsal region, slanting obliquely posterolaterally; tibia I without ventral spines (plate I: 5) . . . . *Salticus scenicus*

1B Abdomen not gray with slanting white stripes 2

2A Tibia plus patella III equal to or longer than tibia plus patella IV 3

2B Tibia plus patella III shorter than tibia plus patella IV 4

3A Leg I longer than leg III; infrequent in trees; adults 5-6 mm long (plate I: 3, 6) . . . . *Evarcha hoyi*

3B Leg I shorter than leg III (plate I: 2) . . . . *Habronattus* spp.

Immatures of a few species have been collected infrequently in our samples. This genus has been revised (Griswold in press). *Habronattus oregonensis* and *H. hirsutus* are occasionally found arboreally in El Dorado National Forest. Female *H. oregonensis* are uniformly fawn-colored without white stripes on the carapace or on the base of the abdomen; males are dark in Oregon and are covered dorsally with iridescent red hairs, with white pubescence over the first row of eyes. Both sexes of *H. hirsutus* have prominent diverging white bands on the anterior carapace. Females have a dark abdomen covered with tawny gray pubescence, a basal transverse white band and longitudinal bands of four triangular white spots. Males have a dark abdomen covered with reddish pubescence; they lack a basal band, but have oblique lateral white bands and tiny white chevrons posteriorly. The males of both species have very modified front legs with heavy fringes of hair.

4A Legs with longitudinal black stripes the entire length of dorsal surfaces; dark gray or black with contrasting color around margin of the carapace and abdomen; occasionally immatures have been encountered arboreally . . . . *Tutelina similis*

Tutelina similis is black in alcohol, but living specimens have a covering of greenish-yellow metallic scales. Adults are 4.5-5.5 mm long.

4B Legs without longitudinal dorsal black stripes 5

5A Sternum narrowed anteriorly; front coxae separated by less than their diameter; carapace elongate (plate I: 4) . . . . *Metacyrba* spp.

Two species of *Metacyrba* (=? *Platycryptus)* may be found arboreally in this region. *Metacyrba taeniola* (southern edge of area only) has a dark brown to black carapace with a thin white marginal band; a brown sternum; all femora with a pair of longitudinal light stripes on the dorsal surfaces; dorsum and sides of abdomen black with a pair of white longitudinal paramedial irregular lines. *Metacyrba californica* (a closely related species found throughout the region) has an orange-brown carapace, yellowish sternum, dark brown abdomen with five connected irregular diamond-shaped pale areas forming a longitudinal band to the posterior (the central three diamonds are laterally extended as thin oblique lines).

5B Sternum not strongly narrowed anteriorly 6

6A Dark integument with iridescent pink or gold scales; carapace and abdomen with white marginal band; infrequent immatures encountered so far; primarily a shrub species of open country; adults 4.5-5.5 mm long . . . . *Sassacus papenhoei*

6B Not with above combination of characters 7

7A Carapace less than two-thirds as wide as long; ocular area appearing wider in front, especially in male; ventral spines on tibia I not crowded into distal two-thirds of segment; carapace black or brown; abdomen dark with a pair of closely set rows of white spots in center on posterior two-thirds of female, all black in male (see fig. 24); sexes strongly dimorphic; labium wider than long; infrequently collected arboreally; adults 4-5 mm long . . . . *Euophrys monadnock*

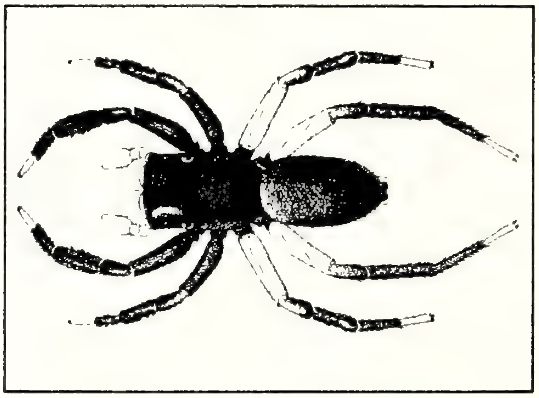


Figure 24—*Euophrys monadnock,* male.

7B Carapace greater than seven-tenths as wide as long; ocular area appearing wider behind, especially in adult *Phidippus* and *Eris;* ventral spines on tibia I crowded into distal two-thirds of segment; carapace rust to buff with black markings connecting eyes; abdominal color variable, but not as above 8

8A Carapace sides strongly bowed, widest medially; small eyes (posterior medians) closer to anterior than to posterior row 9

8B Carapace sides nearly parallel; small eyes nearly equidistant between anterior and posterior rows 10

9A Abdominal dorsum red-brown, sides with three pairs of strong, oblique white bands in females and immatures, males with longitudinal sublateral white stripes; carapace and abdomen with transparent iridescent scales; adult males with forward-projecting chelicerae, fangs strongly sinuous, front leg densely fringed; 5-7 mm long; carapace with pair of longitudinal white stripes; females 6-8 mm long, without black abdominal spots, with three pairs of oblique white bands and prominent marginal band (immatures colored like females); infrequently encountered arboreally in this region; usually on deciduous shrubs (plate I: 1) . . . . *Eris marginata*

9B Cephalothorax and abdomen dark; scale covering not entirely iridescent; abdominal dorsum with central white mark and two pairs of transverse white marks posteriorly or with extensive area of red scales; ocular area with tufts of setae; small eyes much closer to first than third row . . . . *Phidippus* (part)

This genus is poorly studied in California. Very few individuals are encountered in the trees, mostly immature. *Phidippus johnsoni,* adults 8-13 mm long, do occur locally (plate I: 7-8).

10A Less than 4 mm long; carapace and abdomen dark; abdomen may have a few white scales (plate I: 8) . . . . *Phidippus* (young immatures)

10B Not with above combination of characters; body red to yellow or, if dark, abdomen with angular brown or white markings distally (plate J) . . . . *Metaphidippus* spp.

A. Males with enlarged palps for retention of sperm . . . . B

AA. Females and immatures without enlarged palps . . . . F

B. Clypeus and base of chelicerae with dense white pubescence; inhabits Coast Range of Oregon (plate J: 2) . . . . *M. albeolus*

BB. Clypeus dark or with infrequent white scales C

C. Body mainly yellow with scattering of pink spots dorsally; clypeus with scattered white scales; femur of first leg distinctly paler than more distal segments . . . . *M. watonus*

CC. Body predominantly reddish with black markings; clypeus without white scales . . . . D

D. Chelicerae with diagonal stripes of white scales; inhabits Oregon Coast Range and Willamette Valley (plate J: 6) . . . . *M. manni*

DD. Chelicerae without white markings . . . . E

E. Carapace with broad cream-colored bands just below posterior eyes, extending onto thorax; inhabits Great Basin, frequent on juniper (plate J: 8) . . . . *Metaphidippus* n. sp.

EE. Carapace dark, with at most a few white scales; abundant throughout entire montane Western North America (plate J: 5) . . . . *M. aeneolus*

F. With a tuft of stiff black setae below the small pair of eyes; abdomen nearly cylindrical; lightly pigmented, primarily yellow or pink . . . . G

FF. Without a tuft of black setae below smallest eyes; abdomen robust . . . . H

G. Pink; restricted to coast and Coast Range . . . . *M. albeolus*

GG. Yellow; widely distributed in conifer forests (plate J: 4) (best distinguished from the preceding by genital characters) . . . . *M. watonus*

H. Carapace densely covered with yellow scales; scales between central pair of front eyes tan to orange; inhabits Great Basin, frequent on juniper . . . . *Metaphidippus* n. sp.

HH. Carapace with white, transparent, or gray scales on top I

I. Carapace with copper sheen and transparent scales; scales between central pair of anterior eyes orange, distinctly darker than white scales on clypeus; abdomen without prominent central white patch; inhabits Oregon Coast Range and Willamette Valley . . . . *M. manni*

II. Carapace with white or gray scales; scales between central pair of anterior eyes white, similar to scales on clypeus; abdomen with a conspicuous central white patch; widespread and abundant throughout Western North America (plate J: 1, 3, 7) . . . . *M. aeneolus*

Some of the most abundant and widespread arboreal spiders in the Pacific Northwest are members of the genus *Metaphidippus,* currently under study by Wayne Maddison of Harvard University, who has helped us greatly in preparing this section. By far the most abundant species is *M. aeneolus,* known as *M. uteanus* in the Rocky Mountains (Maddison, pers. comm.). At budburst, two size-classes are expected: subadults 4.5 mm long and immatures about 2 mm long. Patterning varies with age (plate J: 1, 3 compared to J: 7), and the transformation to adult male is so striking that it appears to be a different species.

Metaphidippus albeolus is the dominant species in the coastal forests of lodgepole pine and is in turn replaced by *M. californicus* on dense windswept branches on edges of coastal bluffs. *Metaphidippus californicus* is normally found on rock surfaces of the coastal bluffs and tidepools but strays onto the branches of adjacent trees; the male has a gray to black abdomen with two pairs of small, diverging, white diagonal stripes; the female abdomen is gray with two brown spots near the front and two wide, angular, brown bands posteriorly.

Pseudiscius monticola and *Marchena minuta* are small species, generally similar in appearance to immature *Metaphidippus aeneolus;* they are rare and apparently inhabit tree trunks rather than the foliage of conifers. Both species are elongate and dorsoventrally flattened, with nearly parallel sides; they are easily mistaken for the highly variable forms of the youngest *M. aeneolus* or *Metacyrba. Marchena minuta* is distinguished by a diagonal row of five bristles arising from prominent tubercles on the first femur.

Key to the Crab Spiders (Thomisidae, Philodromidae)

Recently revised by Schick (1965) for all of California; specimens not fitting the key, descriptions, or illustrations in every detail should be checked in this reference. Adults are necessary for use of the keys in Schick's monograph.

1A Abdomen with prominent apical tubercle on dorsum (plate K: 7); clypeus strongly sloping, clypeal height far exceeding interocular distance . . . *Tmarus angulatus*

Body a variable mixture of black and white splotches (plate K: 7-8); adults 4.5-6.0 mm long; at budburst, most are submature.

1B Abdomen without medial tubercle; clypeal region not strongly sloping 2

2A Ocular region contrastingly whitened; eye bases tuberculate and prominently confluent; carapace and abdomen white to yellow 3

2B Eye bases not of contrasting white nor confluent, though occasionally tuberculate individually 4

3A Abdomen strongly spinose throughout; anterior lateral eyes and their tubercles larger than anterior median eyes and tubercles; legs strongly spinose . . . . *Misumenops* spp.

This is a diverse genus with many potential species in the Pacific Northwest. Most species inhabit shrub and forb vegetation. The most abundant and widespread species, though infrequent on trees, is *M. celer (=M. lepidus sensu* Schick 1965) (plate K: 6); this species is distinguished by black setae on the carapace. *Misumenops quercinus* (arboreal in oak woodlands), *M. sierrensis,* and *M. importunus* have pale setae on the carapace; they are distinguished only by genital characters. Sexual dimorphism of color pattern is pronounced.

3B Abdomen nearly without pubescence, never spinose (small immatures with scattered black abdominal dorsal pubescence); anterior eyes subequal; legs with a few dorsal or lateral spines . . . . *Misumena vatia*

Male 4.0 mm long; female 8.0 mm long; coloration dimorphic (plate K: 3, 5). This is the only local species and is unlikely to be confused with other genera. *Misumena vatia* is abundant in the forb layer of disturbed forests and infrequently strays into trees.

4A Carapace longer than wide (generally 1.5-2.0 times in larger individuals; 1.2 times in small immatures); abdomen 2.5-5.0 times longer than wide (plate L: 8) . . . . *Tibellus oblongus*

A distinctive genus, its length-to-width ratio is equaled or exceeded only by *Tetragnatha* (plate C: 3, 4). Adults are 6.0-8.5 mm long. *Tibellus oblongus,* principally inhabiting the forb layer, is only occasionally found in trees.

4B Carapace length at most slightly greater than width; abdomen at most 1.[illegible] times longer than wide 5

5A Body bare except for setae; legs III and IV less than two-thirds length of leg I (less pronounced difference in small immatures); black forward-projecting setae around eyes and clypeus 6

5B Body covered with dense pubescence; legs III and IV similar in length to legs I and II; clypeus and eye region without prominent forward-projecting setae (Philodromidae) 8

6A Green (fading to yellow in alcohol) with four small red spots on carapace; eye tubercles pale yellow; legs green but pale amber distally; abdomen, particularly of mature individuals, with a large darkly bordered red patch; a black cardiac mark and bright yellow sides . . . . *Diaea pictilis*

This magnificent species is restricted to the California Coast Ranges; data in Schick (1965) confirm a habitat preference for live oak.

6B Light orange-brown to brown or black; mottled 7

7A Carapace flattened, thoracic groove distinct; anterior eye row nearly straight . . . . *Coriarachne* spp.

Two species of these bark-dwelling spiders are abundant throughout the region. The carapace of *Coriarachne brunneipes* is largely dark brown with a few scattered white maculations, but that of *C. utahensis* (plate K: 1) is extensively marked with white.

7B Carapace distinctly convex, thoracic groove indistinct or absent; anterior eye row distinctly procurved . . . . *Xysticus* spp.

This genus is abundant in many habitats throughout the region, but only two species are common in the trees: *Xysticus punctatus* has an abdominal dorsum with paired orange-brown patches separated by a broad pale median area and an orange-brown carapace. The abdominal dorsum of *X. locuples (=X. malkani)* has paired brown areas separated by an off-white median line and transverse lines; the carapace is dull red-brown. The genitalia of these two species are very distinct (Schick 1965). Adult males of *X. locuples* occur at budburst, but females live through summer. *Xysticus gosiutus,* a species abundant in deciduous shrubs, is frequently found in early regrowth conifers (plate K: 2).

8A Carapace basically unicolored; medial portions dark, nearly as dark as allata; legs with uniform, dense, equidistant spots throughout (plate L: 5) . . . . *Apollophanes margareta*

This common species occurs as subadults, 5-6 mm, and as 2-mm immatures at budburst. Adults are the largest of arboreal crab spiders (6-10 mm), second only to female *Araneus* of all arboreal spiders in the Pacific Northwest. Schick (1965) erects a monotypic genus, *Pelloctanes,* for this species, but the consensus of more recent workers (Dondale and Redner 1975) is to retain it in the genus *Apollophanes.* This species, most easily confused with *Philodromus spectabilis* (plate L: 3), can be distinguished by the absence of contrasting white leg joints in small immatures and the presence of a uniformly brown carapace and a strong anterior cardiac mark in larger immatures.

8B Carapace with darkened sides (allata) bordering a light-colored center . . . . *Philodromus* spp.

A. Cream-colored, with buff to bright orange or pink (often suffused with tan in preserved specimens) allata and lateral abdominal regions (particularly contrasting in mature males) (plate L: 1) . . . . *P. rufus pacificus*

AA. White with purple to maroon markings (often suffused with tan in preserved specimens) . . . . B

B. Abdomen with distinct posterolateral corners and hence strongly diamond-shaped (plate L: 6) C

BB. Abdomen without distinct posterolateral protrusions, definitely not diamond-shaped; posterolateral portions of abdomen without short, dark, dorsally projecting bands; posterior half of abdomen covered by herringbone bands, anteromedially with fainter cardiac stripe; legs often with irregular splotches on most surfaces of femora; small immatures with contrasting white annulations at leg joints; posterior median eyes surrounded by dark maculations (plate L: 3) . . . . *P. spectabilis*

C. Abdomen largely white, pattern indistinct or absent; legs mostly white with dense small maculations (female - plate L: 2) or uniform brown (male), never splotched or banded . . . . *P. quercicola*

CC. Abdomen with small purplish maculations; legs with large splotches or annulations; posterolateral portions of abdomen with contrasting short, dark, dorsally projecting bands; bases of femora with large contrasting regions devoid of purple maculations; with prominent cardiac stripe on all but smallest immatures, with or without a herringbone pattern; posterior median eyes surrounded by clear white integument . . . . *P. speciosus*

Keying out with *P. rufus* is the infrequent *P. rodecki,* found at the western edge of the Great Basin; the abdominal dorsum of *P. rodecki* is covered with patches of orange pubescence interspersed with dark, round punctations. Keying to *P. speciosus* are the similar (and likewise variable in color pattern) *P. josemitensis, P. gertschi* (plate L: 6), and *P. oneida. Philodromus josemitensis* primarily inhabits coastal mountains and is distinguished by the completely darkened ventral surfaces of femora I and II. *Philodromus gertschi* is a similar species of the major mountain axis, but lacks the purple to white blotch pattern on the femora. *Philodromus oneida* inhabits more northern boreal forests and is reliably separated from the other two species only by genital characters. *Philodromus pernix* and *P. californicus* may also be encountered arboreally in the region; these species have a rounded abdomen like *P. spectabilis* but lack pigmentation in the carapace behind the eyes *(P. californicus* has spotted legs; *P. pernix* has splotched legs and black abdominal sides). Genitalia are shown in Schick (1965).

Philodromus, though a diverse genus in this region, has only three species abundant on *Abies. Philodromus rufus pacificus* is 3.0-4.5 mm long as an adult and readily distinguished by coloration; this form is sometimes referred to as *P. rufus* or *P. pacificus. Philodromus spectabilis,* adult length 4.5-6.0 mm, can also be distinguished from most other sympatric species on the basis of coloration. Both *P. rufus pacificus* and *P. spectabilis* are abundant arboreal spiders in the Placerville region; both species occur in two size-classes at budburst, adults and small immatures. Many other local arboreal species are not readily separable from *P. speciosus* without reference to adult genitalia.

Thanatus is a similar genus usually characterized by a prominent white-margined cardiac spot. It generally inhabits the ground and shrub layers. *Thanatus altimontis* (plate L: 4) is abundant on the desert shrubs of the Great Basin and can occasionally be collected from lower branches of conifers.

Acknowledgments

Identification of synoptic specimens was made by W.J. Gertsch with supplemental identifications provided by R.X. Schick (Thomisidae, Philodromidae), V.D. Roth (Agelenidae), N.I. Platnick (Anyphaenidae, Clubionidae, Gnaphosidae), and M. Moody (Araneidae, Linyphiidae). Synoptic reference material is available at Oregon State Unversity, the Southwestern Research Station (American Museum of Natural History), the University of California at Berkeley, and the Museum of Comparative Zoology at Harvard University. Wayne Maddison wrote the couplets separating species of *Metaphidippus* and D. Richman suggested numerous improvements. Partial support for these studies in the Andrews Experimental Forest Long-Term Ecological Reserve was provided by the National Science Foundation (DEB 8012162; BSR 8514325; BSR 8300370). Permission to use the line illustrations was kindly provided by the William C. Brown Company, Dubuque, Iowa.

Glossary

Allata: region of the carapace flanking the middorsal longitudinal axis, frequently contrasting in color to rest of carapace.

Anterior: directed towards the front of the body.

Apophysis: a projection, frequently referring to a bizarre modification of the male palp.

Calamistrum: a comblike row of strong bristles along the margin of metatarsus IV (see figs. 6, 8).

Carapace: the dorsal shield of the anterior half of a spider body.

Cardiac region: middorsal anterior portion of the abdomen, containing the heart; frequently marked externally by a distinctive design.

Chelicerae: most anterior of the body's appendages (see figs. 3, 4, 5); bearing the fangs at their tip.

Chevrons: geometric design of nested, progressively decreasing angle-marks.

Clypeus: region of the carapace between the base of the chelicerae and the anterior median pair of eyes (= upper lip) (see figs. 18, 19).

Colulus: a median, often wart-like appendage just anterior to the spinnerets (see fig. 20).

Cribellum: a broad sclerotized plate medially in front of the spinnerets, functioning as a composite spinneret (see fig. 7); when reduced in size, referred to as a colulus.

Embolus: the elongate spine-shaped tip of the male genital palp, usually darkly melanized and contrasting with the rest of the intromittent organ.

Epigastric furrow: the transverse fold on the anterior portion of the abdomen of most spiders stretching between the entry portals for the two book lungs (see figs. 16, 23).

Femur (plural femora): the third leg joint, usually the longest and most robust leg joint.

Genitalia: the organs of reproduction; the external genitalia of female spiders lie medially between the book lungs and along the epigastric furrow; in male spiders, the apical segment of the palps is modified as an intromittent organ.

Herringbone pattern: frequently used terminology for a long series of angle-markings resembling the axial skeleton of a fish.

Heterogeneous: refers to the coloration pattern of the eyes; some dark and others light.

Homogeneous: refers to the coloration pattern of the eyes; all eight are black or all eight are transparent.

Laterally: towards the side of the body.

Laterigrade: refers to the condition of the first two pairs of legs in crab spiders, in which the anterior legs are rotated with respect to the body so that they lie parallel to the substrate and their morphologically lateral surfaces point dorsally.

Longitudinal: along the midline of the body extending from the eyes to the anus.

Maculated: spotted, splotched.

Median: along the main longitudinal axis of the body.

Median ocular area: the region of the carapace defined with its corners at the two anterior median and two posterior median eyes.

Metatarsus (plural metatarsi): the sixth and next-to-last leg segment.

Ostial markings: contrasting paired markings on the paramedial anterior abdominal dorsum located over the cardiac ostia and therefore subadjacent to the cardiac spot.

Palps: the most anterior pair of leg-like appendages, located between the chelicerae and the first pair of walking legs; modified in adult males as intromittent organs.

Paramedial: adjacent to the median longitudinal axis of the body.

Patella: the fourth leg segment, located between the major femur and tibia segments and resembling a short "knee-joint."

Posterior: towards the rear of the body.

Procurved: referring to a transverse line (such as an eye row or the epigastric furrow) that is deflected posteriorly along the midline and hence the ends point forward (see fig. 23).

Prograde: referring to the usual leg placement of spiders, in which all legs are held in the vertical plane and the morphologically anterior faces all point forward.

Pubescence: a body covering of hair-like structures.

Rebordered: refers to the condition of the labium ("lower lip") in which the anterior edge is greatly thickened and projects ventrally over the surface of the sternum as a ridge (see fig. 22).

Recurved: referring to a transverse line (such as an eye row or the epigastric furrow) that is deflected anteriorly at the midline and hence the ends point backwards.

Spinneret: any of the three pairs (usually) of silk-producing short appendages located at the posterior terminus of the venter (see figs. 14, 15).

Spiracle: of the ventral surface of the body leading into the tracheal system, normally located just anterior to the bases of the anterior spinnerets.

Sternum: sclerotized body surface on the ventral face of the cephalothorax between the leg bases (see fig. 22).

Stridulating organ: any of various noise-making structures on the surface of the body, consisting of a series of adjacent parallel ridges on one body part against which a series of pegs on another body part is rubbed.

Sub- (used as a prefix): almost, close-to.

Subadult: the next-to-last moult in which the reproductive organs are often well developed but still afunctional.

Tarsal comb: the row of comb-like or feather-like setae on tarsi IV of the Theridiidae (see fig. 21).

Tarsal tuft: the tuft of adhesive pubescence between the tarsal claws of most climbing and foliage-dwelling spiders (see fig. 13).

Tarsus (plural tarsi): the final leg joint bearing the claws.

Thoracic groove: a medial thickening in the dorsal cuticle, often accompanied by a depression in the vault of the carapace and strong melanization, from which an internal apodeme extends to anchor the leg muscles.

Tibia (plural tibiae): the fifth leg segment, usually the second longest and second most robust.

Trichobothria: a series of extremely long setae on the apical leg segments extending out at right-angles from the leg (see figs. 8, 17).

Trochanter: the second leg segment, tiny and at the base of the femur; in some groups, a conspicuous notch along its basal border with the coxa is used as a prominent diagnostic character.

Vermiform: irregularly elongate, "worm-shaped."

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Moldenke, Andrew R.; Fichter, Becky L.; Stephen, William P.; Griswold, Charles E. A key to arboreal spiders of Douglas-fir and true fir forests of the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-207. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 48 p.

This illustrated key for identifying spiders inhabiting true fir and Douglas-fir is based on extensive collections from throughout the three North American Pacific Coast States. Details of the age classes present at budburst and the season in which to expect adults are presented for all species. This paper is written for people unfamiliar as well as familiar with spider taxonomy; a glossary of all technical terms is included. References to pertinent technical literature are also included.

Keywords: Keys (spider), spiders, Douglas-fir, true fir, Pacific Northwest.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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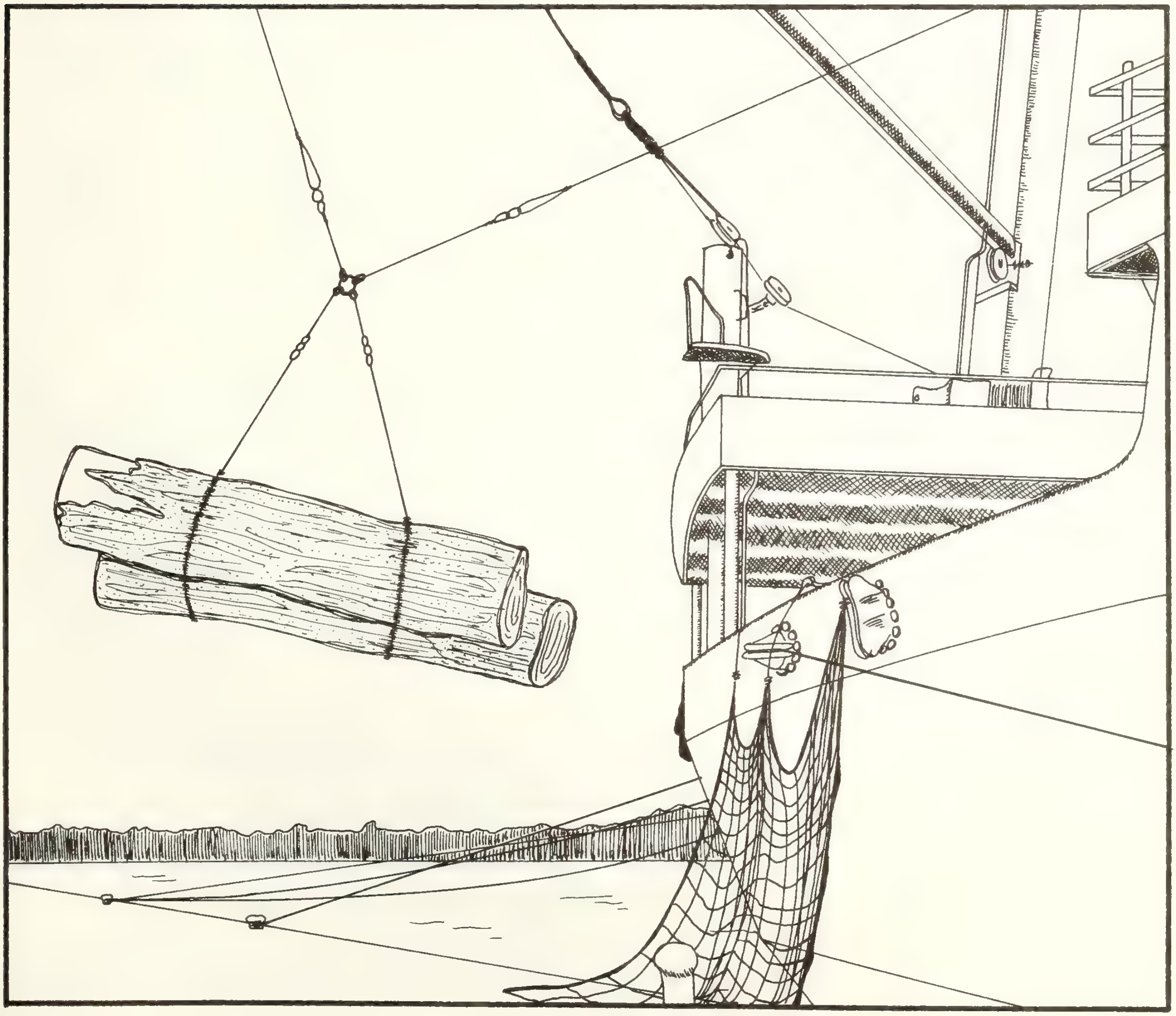
Report
PNW-GTR-208

Log Export Restrictions of the Western States and British Columbia

Judith A. Hines



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This publication is a revision of two publications with the same title, Research Papers PNW-91 (Austin 1969) and General Technical Report PNW-63 (Lindell 1978).

ABSTRACT

Hines, Judith A. 1987. Log export restrictions of the Western States and British Columbia. Gen. Tech. Rep. PNW-GTR-208. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 13 p.

The export of unprocessed timber is restricted from lands managed by the Forest Service, U.S. Department of Agriculture, and the Bureau of Land Management, U.S. Department of the Interior, in the West. In addition, the Forest Service and the Bureau of Land Management have implemented regulations to ensure that Federal timber is not substituted for private timber.

The export of unprocessed timber is also restricted from lands managed by the States of Alaska, Oregon, California, and Idaho. As a result of a suit against the State of Alaska and subsequent appeals, however, the attorneys general of the States of Alaska, Oregon, and Idaho have rendered opinions that language restricting exports should be removed from State timber sale contracts, contending that no enforcement is defensible until the litigation is resolved. The State of California attorney general's opinion is that "while California's restriction probably could not stand up to judicial scrutiny, the California constitution says a State agency has no power to declare a statute unenforceable. Therefore, until a California or Federal court specifically invalidates California code we are required to enforce the terms of the contract." The States of Washington and Montana impose no restrictions on exports.

The export of logs or chips from British Columbia is permitted when it has been established that these are surplus to domestic needs. Certain species have been declared nonsurplus. Export approval criteria are most stringent in the southern coastal portion of the Province.

KEYWORDS: Import/export (forest products), trade policy (international, legislation.

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INTRODUCTION

This report presents the main features of log export restrictions imposed by various State and Federal agencies as well as by British Columbia. Restrictions are summarized by political jurisdiction on page 12. Some of the information here is repeated from the earlier publications (Austin 1969, Lindell 1978).

FEDERAL LEGISLATIVE HISTORY

Restriction of Log Exports From Federal Lands

On April 16, 1968, the Secretaries of Agriculture and the Interior issued joint orders restricting the volume of timber that could be harvested and exported from Forest Service, U.S. Department of Agriculture, and Bureau of Land Management, U.S. Department of the Interior, lands in unprocessed form.[1/]

The Secretaries limited the volume of timber that could be exported from Federal lands to 350 million board feet annually. They deemed this restriction necessary for maintaining a viable domestic wood-processing industry.[2/]

The Secretaries' 350-million-board-foot quota was legislated, effective January 1, 1969, by an amendment to the Foreign Assistance Act of 1968 (82 Stat. 966). The amendment, commonly referred to as the "Morse Amendment," section 921 of the Housing and Urban Development Act of 1970 (84 Stat. 1817), extended the expiration date for this provision to December 31, 1973.

[1/] A determination by the Secretary of Agriculture concerning primary processing of timber from National Forests of the Pacific Northwest. Specified in a memorandum from the Secretary of Agriculture to the Chief of the Forest Service, April 16, 1968.

[2/] Plan for requiring domestic primary manufacturing of logs from National Forest land in the Pacific Northwest. Response to the April 16, 1968, memorandum of the Secretary of Agriculture.

A provision attached to the Department of the Interior and Related Agencies Appropriation Act, 1974 (P.L. 93-120, October 4, 1973), in effect prohibited the export of unprocessed timber harvested from Federal lands in the West. The act stated that:

> No part of any appropriation under this Act shall be available to the Secretaries of the Interior and Agriculture for use for any sale hereafter made of unprocessed timber from Federal lands west of the 100th Meridian in the contiguous 48 States which will be exported from the United States, or which will be used as a substitute for timber from private lands which is exported by the purchaser: Provided, that this limitation shall not apply to specific quantities of grades and species of timber which said Secretaries determine are surplus to domestic lumber and plywood manufacture needs.

This provision was attached to all subsequent Interior and related agencies appropriation acts.

The provision also prohibited purchasers from using timber harvested from Federal lands in their processing facilities while they were exporting non-Federal timber that could have been used. This practice is termed "direct substitution." In a February 1974 letter to the Chief of the Forest Service, however, the Chairman, Subcommittee on Interior and Related Agencies, House Committee on Appropriations, explained that the committee intended to allow historic patterns of trade to continue without disruption. The chairman said the provision was intended to prohibit firms in the export trade from increasing their log exports in the future through direct substitution.

In March 1974, the Forest Service established regulations implementing this provision, including the restriction on log substitution (Code of Federal Regulations, Title 36, Chapter II, Part 221.25). The Forest Service defined "purchaser" as the person who purchases National Forest timber directly from the Forest Service. This definition precludes the purchaser from substituting or replacing private exported timber with National Forest timber. The regulations do not prevent others (third parties) from buying National Forest timber from the purchaser and substituting it for the private timber they export (Code of Federal Regulations, Title 36, Chapter II, Change part number from 221.25 to 223.10, December 17, 1979). This practice is termed "third-party substitution." The Acting Associate Deputy Chief of the Forest Service in a letter to the General Accounting Office dated January 11, 1984, defined third-party substitution as follows:

> Third-party substitution is the acquisition of National Forest timber from a National Forest timber sale purchaser by a firm which is not eligible to purchase the National Forest timber directly because direct purchase would constitute substitution under 36 CFR 223.160.

On July 26, 1983, the chairman of the Senate Committee on Appropriations and the chairman of the Subcommittee on Interior and Related Agencies, Senate Committee on Appropriations, requested the General Accounting Office to provide them with information on the magnitude and potential impacts of tighter restrictions on export of Forest Service logs. In a report published on January 28, the U.S. General Accounting Office (1985) provided the following information:

> Federal law restricts the export of unprocessed timber cut from National Forests in the western half of the United States. Also purchasers of National Forest timber are restricted from substituting timber harvested from Federal lands for privately owned timber that they export. GAO reviewed the magnitude of and the potential impacts from extending the substitution restriction to cover third parties who subsequently acquire Forest Service timber from the original purchasers--an export industry commonly referred to as third-party substitution.
>
> According to the Forest Service and timber industry association, third-party substitution approximates 100 million board feet annually in the western United States. They said that if the practice were banned, some companies could acquire National Forest timber at lower prices because of decreased demand and competition, and the lower prices would result in less government revenues. Also, a ban could disrupt traditional log markets and business practices.
>
> The Forest Service believes it could not enforce a ban on third-party substitution without additional legal authority and staff.

Restriction of Redcedar Exports From Federal and State Lands

Export of western redcedar and waney (lacking wood on one or more corners) lumber has been prohibited from State and Federal lands since late 1982, by the Export Administration Act of 1979 and the regulations that implement the act (15 CFR 377.7). Federal and State lands in Alaska, and Indian trust lands everywhere, are not affected. All exporters of this kind of material, however, are required to obtain export licenses from the International Trade Administration, Office of Export Administration.

NATIONAL FORESTS OUTSIDE ALASKA

On April 20, 1981, the Forest Service published revised regulations in the Federal Register regarding the export of timber from National Forest System lands and the substitution of such timber for private timber to be exported by the purchaser. This document further clarified the definition of tributary area and incorporated a definition of unprocessed western redcedar. The regulations (Code of Federal Regulations, Title 36, Chapter II, Part 223) include the following major provisions:

1. Export is either direct or indirect export to a foreign country. Unprocessed timber is exported directly when the exporter is the purchaser of National Forest timber. Timber is exported indirectly when export results from a sale to another person or from a subsequent transaction.
2. Historic level is the average annual volume of unprocessed timber purchased or exported in calendar years 1971, 1972, and 1973.
3. Private lands are lands held or owned by a private person.
4. Nonprivate lands include, but are not limited to, lands held or owned by the United States, a State or political subdivision thereof, or any other public agency, or lands held in trust by the United States for Indians.
5. Substitution of public timber for exported private timber occurs when:
   a. a buyer of National Forest timber increases purchases in any calendar year 10 percent above the historic level and in the same calendar year exports unprocessed timber from private land in the tributary area; or
   b. a purchaser of National Forest timber increases exports of unprocessed timber from private land in any tributary area more than 10 percent above the historic level in any calendar year while having National Forest timber under contract.

6. Tributary area is the geographic area from which unprocessed timber is delivered to a specific processing facility or complex.
7. Unprocessed timber does not mean pulp (utility) grade logs and Douglas-fir special cull logs.
8. Processed timber is:
    a. Lumber and construction timbers, regardless of size, sawn on four sides.
    b. Chips, pulp, and pulp products.
    c. Green veneer and plywood.
    d. Poles, posts, or piling cut or treated for use as such.
    e. Cants cut for remanufacture, 8-3/4 inches or less in thickness.
9. Unprocessed western redcedar is trees or portions of trees of that species that have not been processed into:
    a. Lumber of American Lumber Standards grades of number 3 dimension or better, or Pacific Lumber Inspection Bureau Export R-List grades of number 3 common or better.
    b. Chips, pulp, and pulp products.
    c. Veneer and plywood.
    d. Poles, posts, or piling cut or treated with preservatives and not intended to be further processed.
    e. Shakes and shingles.

NATIONAL FORESTS IN ALASKA

Federal land in Alaska is excluded from the annual Interior and Related Agencies Appropriation Act pertaining to log exports. The Forest Service limits the export of unprocessed timber from National Forests in Alaska under general authority of the Organic Administration Act of June 4, 1897 (16 U.S.C. 475, 551), National Forest Management Act of October 22, 1976 (90 Stat. 2949 (16 U.S.C. 472a et seq.) and 36 CFR 223.161).

The Regional Forester for Alaska set the following policy governing the processing of Alaska National Forest timber (U.S. Department of Agriculture, Forest Service, Alaska Region 1986):

1. Export of spruce and hemlock logs is prohibited (since 1926).
2. Export of Alaska-cedar and western redcedar logs is allowed.
3. In limited circumstances, logs from sales appraised at less than $2,000 may be exported.
4. Export of other species is allowed from timber sales in which more than half the volume is salvage material. This provision was renewed annually from 1934 to 1986; it may not be continued.

5. Beach logs administratively disposed of with or without charge may be exported.
6. Export of logs, cordwood, bolts, and similar products requiring primary manufacture elsewhere is prohibited.
7. Before any material may be exported, approval must be granted by the Regional Forester.

In 1986, the maximum thickness allowed for export cants was relaxed from 8-3/4 to 12 inches.

BUREAU OF LAND MANAGEMENT LANDS OUTSIDE ALASKA

On July 28, 1976, the Bureau of Land Management published regulations in the Federal Register about the export of timber from Federal lands administered by the U.S. Department of the Interior. The regulations (Code of Federal Regulations, Title 43, Chapter II, Part 5400.5) contain the following major provisions:

> The Department of the Interior and Related Agencies Appropriation Act, 1976 (Public Law 94-165) prohibits the use of funds appropriated thereunder for sale of unprocessed timber from Federal lands west of the 100th Meridian in the contiguous 48 States which will be exported from the United States, or which will be used as a substitute for timber from private lands which is exported by the purchaser. The law also provides that the export restriction shall not apply to specific quantities of grades and species of timber which the Secretary of the Interior determines to be surplus to domestic lumber and plywood manufacturing needs.
>
> Unprocessed timber is:
> a. any logs except those of utility grade or below, such as saw logs, peeler logs, and pulp logs;
> b. cants or squares exceeding 8-3/4 inches in thickness that will be remanufactured;
> c. split or round bolts, or other roundwood not processed to standards and specifications suitable for end product use.
>
> Federal lands are: all lands administered by the Department of the Interior west of the 100th Meridian in the contiguous 48 States with the exception of tribal and trust allotted lands managed by the Bureau of Indian Affairs on behalf of the Indians.

Substitution means:

a. The purchase of a greater volume of Federal timber by an individual purchaser than has been the [purchaser's] historic pattern within 12 months of the sale of export [logs] by the same purchaser or a greater volume of [the purchaser's] historic pattern during the preceding 12 months, exclusive of Federal timber purchased by negotiated sale for right-of-way purposes, and

b. The increase of both the purchase of Federal timber and export of timber from private lands tributary to the plant for which Bureau of Land Management timber covered by a specific contract is delivered or expected to be delivered.

BUREAU OF LAND MANAGEMENT LANDS IN ALASKA

The Bureau of Land Management does not have a major timber sale program in Alaska. A few small sales are made only for local, domestic needs. Consequently, no regulations have been written about the export of logs from Bureau of Land Management lands.

BUREAU OF INDIAN AFFAIRS

The Department of the Interior ban on log exports does not apply to lands managed on behalf of the Indians. Individual reservations, however, may impose restrictions. None existed in 1986.

Unprocessed timber may not be exported from one 61,360-acre area of land managed on behalf of the Indians; this area, known as the "McQuinn Strip," borders the north and west sides of the Warm Springs Reservation of Oregon. Ownership of this strip was disputed for many years because of an earlier contested survey. Finally, in 1972, title to the former Federal land that formed parts of two National Forests was ceded to the Confederated Tribes of the Warm Springs Reservation of Oregon (Act of September 21, 1972; P.L. 92-427, S.2969).

That 1972 act contained language that retained existing marketing patterns for timber from the strip until January 1, 1992 (Harved 1985). Among other things, the act specified that timber from the strip must be designated for primary manufacture in the United States. In administering the act, the Bureau of Indian Affairs adopted the Forest Service definition of processed versus unprocessed timber to define primary manufactured items; that is, lumber, chips or pulp, green veneer, poles and piling, or cants 8-3/4 inches in thickness or less.

GENERAL EXPORT POLICIES OF THE WEST COAST STATES

Alaska, California, Idaho, and Oregon have enacted legislation restricting export of unprocessed logs. These States have had to review their policies in light of a recent U.S. Supreme Court decision about the State of Alaska.

Alaska

State regulations have granted the Director of the Department of Natural Resources of Alaska the option of restricting the primary manufacture of State-owned timber to the State. These regulations have been disputed (Frank 1985). South Central Timber Development, Inc. brought suit against the State of Alaska in Federal District Court on the grounds, among others, that Alaska's in-State primary manufacturing requirement violated the implications of the Commerce Clause of the U.S. Constitution (South Central Timber vs. Wunnicke). The District Court found that the primary manufacturing requirement did violate the Commerce Clause, and that Congress had not consented to the requirement. The U.S. Court of Appeals for the Ninth Circuit unanimously reversed the District Court. In a May 22, 1984, decision, the U.S. Supreme Court held that a State restriction on the place of "primary manufacture" of State-owned timber constitutes an unconstitutional burden on interstate commerce; the Court thereby upheld the decision of the District Court.

In 1984, the State of Alaska filed a notice of appeal with the Ninth Circuit Court of Appeals (Frank 1986). The Circuit Court, however, refused to reconsider the case. Meanwhile, a memorandum issued on August 2, 1984, by the Alaska Department of Natural Resources said, "Until further notice, refrain from issuing prospectus, notice, and contracts that, as a requirement of sale, state that timber harvested from State forest lands will require primary manufacture." (Wallingford 1984). Thus, the State is not limiting log exports.

California

In 1974, the State of California directed that "timber from state forests shall not be sold to any primary manufacturer, or to any person for resale to a primary manufacturer, who makes use of such timber at any plant not located within the United States unless it is sawn on four sides to dimensions not greater than 4 inches by 12 inches" (California Public Resources Code, Section 4650.1).

In a policy statement on June 21, 1984, the California attorney general's office responded to the U.S. Supreme Court's Alaska decision (Fago 1986):

> ...until such time as a California or Federal court specifically invalidates the portions of PRC4650.1 which deal with foreign commerce, we should continue to enforce them. If anyone asks our opinion on the subject, it is that we are required by statute and the state constitution to enforce the terms of the contract. Until such time as a court orders us to do otherwise or the Legislature removes the requirement, we will continue to do so.

Idaho

The Idaho State Board of Land Commissioners (Idaho Code, 58-403) is required by statute to put certain sales restrictions on all State timber sales. The pertinent language reads:

> The state board of land commissioners are hereby required when contracting for the sale of timber on lands owned by the state to prescribe that the timber cut from said lands under said contract shall be manufactured into lumber or timber products within the state of Idaho; provided, that the sale of any timber to be used in the manufacture of wood pulp shall be excepted from the above provision.

The State of Idaho, alluding to the Alaska case, stated (Attorney General Opinion, 84-9):

> Idaho Code (58-403) is even more restrictive than the Alaska regulation in that the land board must restrict rather than may restrict timber exports; on the other hand, the Idaho statute does not restrict the export of pulp logs, whereas the Alaska regulation allows the director to do so.
>
> Because the Alaska regulation and the Idaho Code seek to accomplish the same thing - restrict the first step in the manufacture of state-owned timber to state businesses - that part of the Idaho Code requiring a contractual export restriction is clearly unconstitutional and should not be enforced.

> Therefore, the Idaho State Board of Land Commissioners and the Idaho State Department of Lands should cease enforcement of the export restriction in all existing contracts and delete the offending statutory language in future timber sale contracts.

Montana

Small volumes of softwood logs normally flow from the Montana Customs District into Canada each year. The Montana Customs District includes all ports in Montana. Montana imposes no restrictions on the export of unprocessed timber (Johnson 1985).

Oregon

By an emergency act passed in 1963 (Oregon Resources Code 526.805 and 526.835), the State of Oregon determined that all timber sold by the State or any of its political subdivisions must receive primary processing in the United States unless the State Department of Forestry has granted an export permit. Primary processing was defined by the act as "that stage of manufacture next beyond the log form of said timber."

In an opinion dated July 31, 1984, the Attorney General rendered the following response to a question posed by the State Forester (Frohnmayer 1982):

> The Attorney General has previously concluded that Oregon's unprocessed log export ban...is probably unconstitutional. What is the effect, if any, of the recent decision of the U.S. Supreme Court in South Central Timber vs. Wunnicke, et al.? The Supreme Court's decision does not change our conclusion that the Oregon statutes are probably unconstitutional and that no enforcement action should be undertaken under these statutes until the South Central Timber litigation is concluded.

Washington

Washington imposes no restrictions on export of timber from lands managed by the State. The most recent referendum was in 1968 when voters defeated initiative measure 32, which would have required that all timber from State-managed lands receive primary manufacture within the State (Hoppala 1985).

British Columbia

Since 1901, the forestry laws and policies of British Columbia have required that timber produced on Crown lands or wood residue produced from such timber be used or manufactured in the Province. In 1906, the constraint was extended to Crown-granted land. Current law (1980 Forest Act, Chapter 140, Part 12) requires that timber from Crown land be used in the Province as unprocessed wood or as lumber or sawn wood products other than lumber, manufactured to an extent required by the Minister of Forests; shingles or fully manufactured shakes; veneer, plywood, or other wood panel products; pulp, newsprint, or paper; peeled poles and piles less than 28 cm (about 11 inches) in diameter and fenceposts; Christmas trees; sticks and timber with diameter less than 15 cm (about 6 inches); ties; or mining timbers.

Exemptions may be granted by either the Minister or the Lieutenant Governor in Council. The Minister may authorize exemptions of volumes of harvested logs up to 15 000 cubic meters (about 3.3 million board feet) for each application. The Lieutenant Governor in Council may authorize the exemption of timber that has been harvested or of standing timber, in unlimited volumes. Exemptions, however, will not be granted unless the Minister or Lieutenant Governor in Council is satisfied that (1) the timber or wood residue is surplus to timber-processing requirements in the Province, or (2) the timber or residue cannot be processed economically in the vicinity of production and cannot be transported economically to a processing facility elsewhere in the Province, or (3) the exemption would prevent the waste of or would increase use of timber extracted from Crown lands.

Exemption from the export constraint has been given to timber within the Mid Coast, North Coast, and Queen Charlotte Timber Supply Areas through March 1988, provided that the timber is surplus to the requirements of timber-processing facilities in the Province, with the determination to be made by local officials of the Ministry of Forests and Lands. Elsewhere along the coast, exemption rules are more stringent, requiring advertising for offers from timber processors; review of resulting prices by the Ministry's headquarters; and with export of upper grades of spruce, Douglas-fir, hemlock, and balsam (true firs) precluded.

Certain species may not be exported from any part of the Province. They are redcedar and yellow-cedar.

SUMMARY OF LOG EXPORT RESTRICTIONS[3]

Geographic area and lands affected	General limitations	Exemptions	Definition of primary processing	Definition of substitution
U.S. Federal and State lands except those in Alaska	No export of unprocessed western redcedar		Lumber without wane, chips and pulp products, veneer and plywood, poles and piling, shakes and shingles	
National forests in contiguous 48 States west of 100th Meridian	No export of unprocessed National Forest timber nor substitution for timber exported from private lands	Port-Orford cedar, Alaska yellow-cedar	Cants 8-3/4 inches or less thick; lumber and squares; chips; pulp, green veneer, and plywood; poles and piling	Compared with historical levels, the purchaser continues to export and increases purchase of National Forest timber
Bureau of Land Management lands	No export of unprocessed BLM timber nor substitution for exported timber from private lands	Port-Orford cedar, Alaska yellow-cedar	Cants 8-3/4 inches or less thick; lumber and squares; chips; pulp, green veneer and plywood; poles and piling	Compared with historical pattern, both purchase of BLM timber and export of private timber increase
National Forests in Alaska	No export of unprocessed timber from State	Alaska yellow-cedar; beach logs; sales under $2,000 value that are salvage, or minor species lacking local demand, including western redcedar	Cants 8-3/4 inches or less thick (12-inch maximum on trial basis); green veneer and plywood; poles and piling	Not applicable
Alaska, State-owned lands	No restriction			
California, State-owned lands	Restrictions enforced			
Idaho, State-owned lands	No restriction			
Oregon, State-owned lands	No restriction			
British Columbia, all lands	No export of red or yellow cedars or of upper grades of other commercial softwoods	None for cedars; other species exempted in Mid Coast, North Coast, Queen Charlotte Areas	Lumber meeting wane requirements for No. 3 common (utility) grade under export "R" list	

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[3] See the text for definitions and more complete description of rules.

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The export of unprocessed timber is restricted from lands managed by the Forest Service, U.S. Department of Agriculture, and the Bureau of Land Management, U.S. Department of the Interior, in the West. In addition, the Forest Service and the Bureau of Land Management have implemented regulations to ensure that Federal timber is not substituted for private timber.

The export of unprocessed timber is also restricted from lands managed by the States of Alaska, Oregon, California, and Idaho. As a result of a suit against the State of Alaska and subsequent appeals, however, the attorneys general of the States of Alaska, Oregon, and Idaho have rendered opinions that language restricting exports should be removed from State timber sale contracts, contending that no enforcement is defensible until the litigation is resolved. The State of California attorney general's opinion is that "while California's restriction probably could not stand up to judicial scrutiny, the California constitution says a State agency has no power to declare a statute unenforceable. Therefore, until a California or Federal court specifically invalidates California code we are required to enforce the terms of the contract." The States of Washington and Montana impose no restrictions on exports.

The export of logs or chips from British Columbia is permitted when it has been established that these are surplus to domestic needs. Certain species have been declared nonsurplus. Export approval criteria are most stringent in the southern coastal portion of the Province.

KEYWORDS: Import/export (forest products), trade policy (international, legislation.

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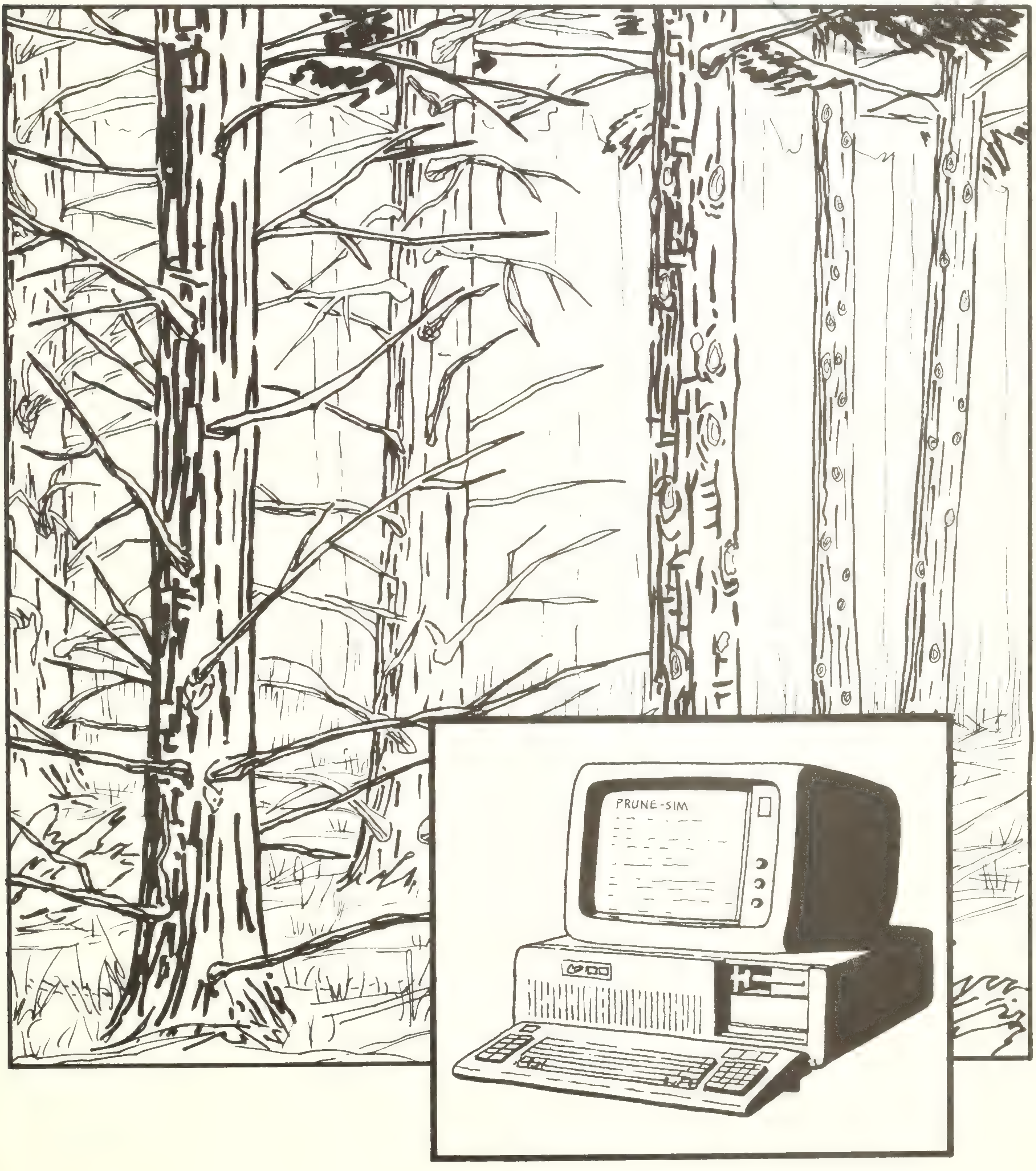
PRUNE - SIM Users Guide

Roger D. Fight, James M. Cahill, Thomas A. Snellgrove, and Thomas D. Fahey



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Abstract

Fight, Roger D.; Cahill, James M.; Snellgrove, Thomas A.; Fahey, Thomas D. 1987. PRUNE-SIM users guide. Gen. Tech. Rep. PNW-GTR-209. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

PRUNE-SIM is a spreadsheet template (program) that allows users to simulate a financial analysis of pruning coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*). The program estimates the increase in product value resulting from pruning the butt 17-foot log. Product recovery information is based on actual mill experience with pruned and unpruned logs for both sawn and peeled products. Users must supply tree descriptions from sources of growth and yield information and product prices. The program calculates the difference in value for trees and stands with and without pruning. The present value of this difference represents the maximum amount that could be spent on pruning without reducing the rate of return on the investment below the specified rate. The LOTUS 1-2-3 spreadsheet program was used to develop PRUNE-SIM. The user needs a basic knowledge of spreadsheets to use this program.

Keywords: Simulation, pruning, Douglas-fir (coast), forest product value, product recovery.

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Introduction

During the last four decades in which coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) has been managed, pruning has often been suggested as a forest-management tool. The effects of pruning in young-growth stands of Douglas-fir have been documented in numerous studies (for example, Dimock and Haskell 1962, Dobie and Wright 1978, Fensom 1957, McBride 1961), and the literature supports a common theme—pruning is the only way to ensure the growth of significant volumes of clear wood in intensively managed stands. Given the short harvest cycles used in current management plans and the limb retention characteristics of Douglas-fir, the growth of clear wood in unpruned young-growth stands is minimal. What has not been well documented is the lumber and veneer grade recovery from pruned logs and the financial returns that can be expected from pruned stands. The purpose of this report is to document a computer program that can be used to analyze the financial return when pruning is applied to a wide range of management regimes.

PRUNE-SIM is a spreadsheet template (program) that can be used to simulate a financial analysis from pruning coast Douglas-fir. The program estimates the increase in product value from pruning 17-foot butt logs. It is based on lumber and veneer volume and grade recovery information reported by Cahill and others (in press). The spreadsheet requires tree descriptions from sources of growth and yield information such as DFSIM (Curtis and others 1981), TASS (Mitchell and Cameron 1985), and Technical Bulletin 201 (McArdle and others 1961). Besides the tree descriptions, users must supply prices by product grade. The spreadsheet will simulate the difference in value for trees and stands with and without pruning. The present value of this difference represents the maximum amount that could be spent on pruning under the assumed conditions without reducing the rate of return on the investment below the specified rate.

The LOTUS 1-2-3 spreadsheet program was used to develop PRUNE-SIM.

Cautions

Three cautions should be observed when this program is used:

1. Users should exercise judgment when doing analyses outside the range of the tree sizes sampled and should remember that the recovery estimates are based on pruning of the first 17-foot butt log.
2. Users should be aware that additional costs of managing pruned stands that occur after the stands are pruned are not considered in this analysis.
3. Users should recognize the uncertainties of predicting future prices of clear wood products.

The trees on which the recovery information is based came from a range of sites, but from a small geographic area. The stands sampled were of natural origin and had been repeatedly thinned but were maintained at denser stocking levels than is now considered desirable. Figure 1 shows diameters of sample trees at time of pruning and at time of harvest.

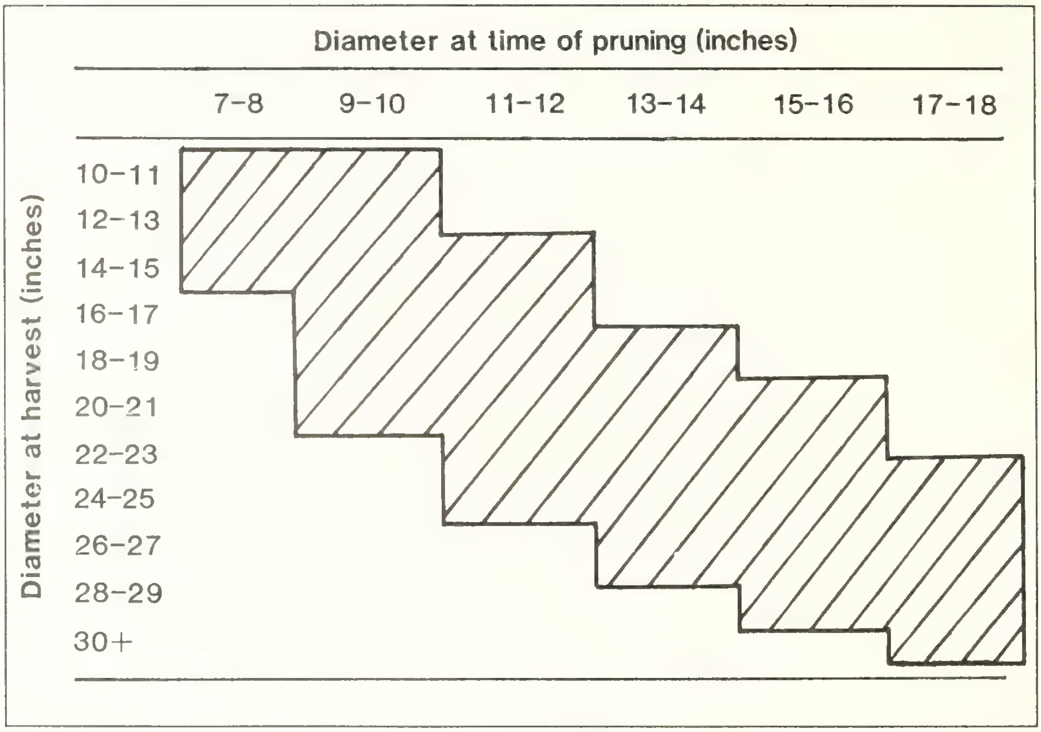


Figure 1—Distribution of sample trees by DBH when trees were pruned and DBH when trees were harvested.

We have no recent cost information on pruning; thus, PRUNE-SIM determines the maximum amount that could be spent on pruning without reducing the return below the specified rate. Additional costs, however, are ignored in these calculations; for example, additional recordkeeping will be required. In a reasonably competitive stumpage market, buyers will be willing to pay a premium for pruned logs that reflects the increase in value resulting from recovery of clear wood products. This is the rationale for using the difference in product value plus the difference in costs of harvesting and manufacturing as the basis for evaluating the returns from pruning. Convincing buyers of the quality of pruned logs may require records showing tree or stand descriptions. Even if the trees obviously were pruned, documented proof of the size of trees at time of pruning may be necessary so that the amount of clear wood can be estimated.

The characteristics of clear wood products produced from pruned young-growth Douglas-fir are different from similar products from old-growth Douglas-fir. One key difference is appearance. As long as clear wood products from old growth are available, the market is likely to be biased against clear wood from pruned young growth. Once clear wood from old growth is no longer available in sufficient quantity to meet the demand without large price increases, however, the bias against young growth should diminish.

How To Use PRUNE-SIM

Figure 2 shows the general layout of the PRUNE-SIM spreadsheet program. The spreadsheet consists of five blocks, each filling one screen width. The five blocks and a brief description are:

1. Lumber. Values for pruned saw logs are computed. This block of the spreadsheet is divided into two sections: lines 1-39 contain the input needed to run the program and the output; lines 41-66 contain the equations used to make the computations.
2. Veneer. Values for pruned veneer logs are computed. This block of the spreadsheet is similar to the one for lumber: lines 1-39 contain the input and output; lines 41-66, the equations used to make the computations.
3. Log diameters. A tree profile equation is used to estimate the diameters of the 17-foot butt log at the time of pruning and at the time of harvest. Total height and DBH (diameter at breast height) are independent variables in the profile equation.
4. Summary output. This block is for storing the results of PRUNE-SIM runs. Users may simulate pruning under a variety of assumptions and store the results for later analysis.
5. "Macro." This block contains a series of commands that allow users to analyze pruning under two price assumptions. Results are automatically stored in block 4.

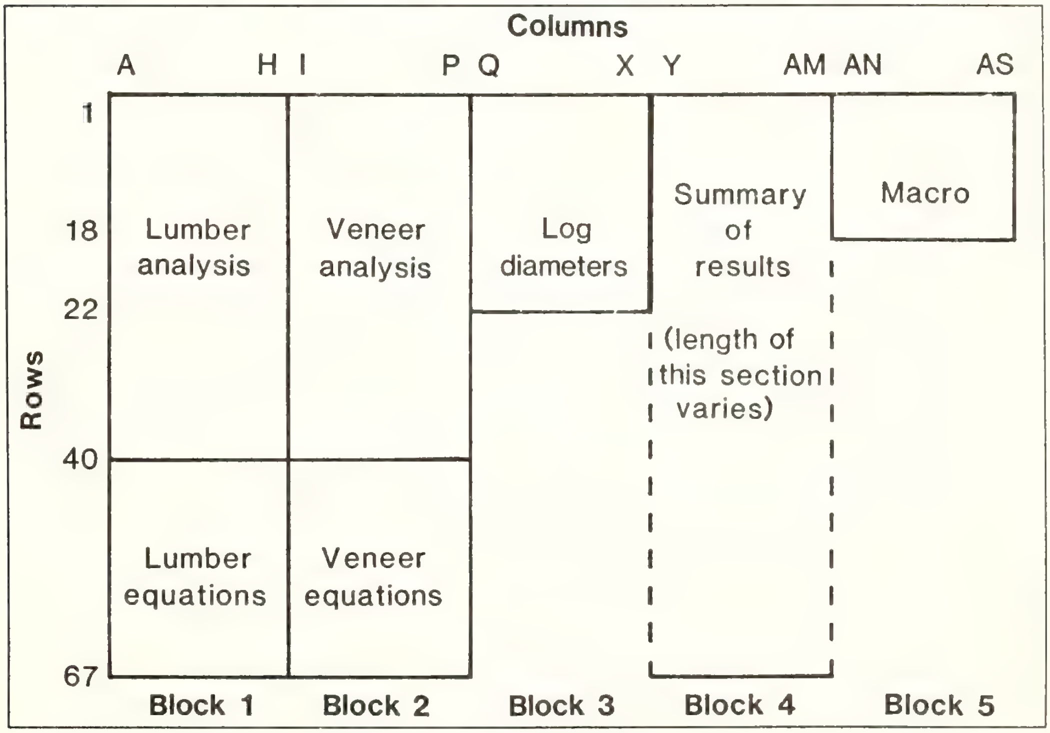


Figure 2—General layout of the PRUNE-SIM spreadsheet. Letters and numbers refer to columns and rows in the spreadsheet.

Use of PRUNE-SIM is demonstrated by the following:

Program input and program output. The general information needed to run the program and the output generated by the program will be illustrated with the lumber portion of the spreadsheet (fig. 3).

Intermediate calculations. The intermediate calculations made by the program are reviewed (fig. 4). This section provides users with a detailed view of the computations made in the PRUNE-SIM spreadsheet.

Veneer analysis. The format for the veneer portion of the spreadsheet is essentially the same as for lumber (fig. 5).

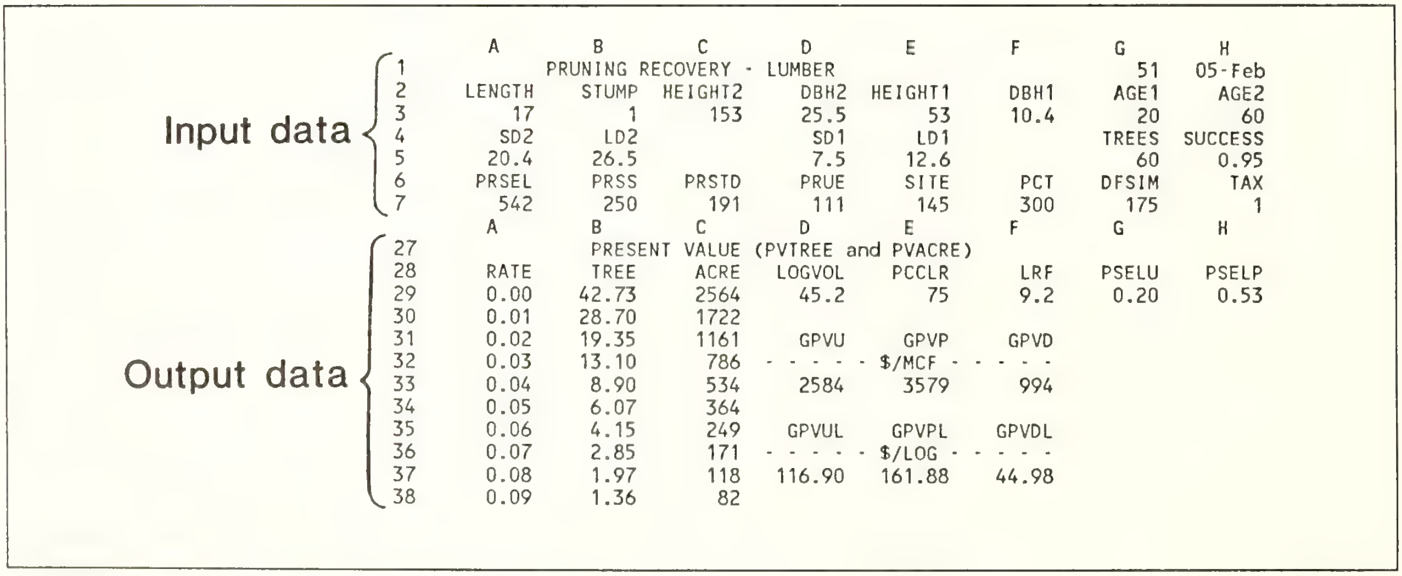
Log diameters. The tree profile equation used to estimate log diameters at the time of pruning and at the time of harvest is discussed (fig. 6).

Average diameter of pruned trees. A technique that converts the average stand DBH to the average DBH of the pruned trees within a stand is discussed (fig. 7).

Macro feature in PRUNE-SIM. The macro feature allows users to make several PRUNE-SIM runs and store the results for further analysis (figs. 8, 9, and 10).

1. Program Input and Program Output

Figure 3 is an example, based on lumber, of an abbreviated spreadsheet. This figure shows only the information needed as input and the results portion of the spreadsheet. All the input is contained in rows 1-7. Five types of information are needed to run the program:



```
                        A         B         C         D         E         F         G         H
               1              PRUNING RECOVERY - LUMBER                               51    05-Feb
               2       LENGTH     STUMP   HEIGHT2      DBH2   HEIGHT1      DBH1      AGE1      AGE2
               3           17         1       153      25.5        53      10.4        20        60
Input data     4          SD2       LD2                 SD1       LD1               TREES   SUCCESS
               5         20.4      26.5                 7.5      12.6                  60      0.95
               6        PRSEL      PRSS     PRSTD      PRUE      SITE       PCT     DFSIM       TAX
               7          542       250       191       111       145       300       175         1
                        A         B         C         D         E         F         G         H
              27                  PRESENT VALUE (PVTREE and PVACRE)
              28         RATE      TREE      ACRE    LOGVOL     PCCLR       LRF     PSELU     PSELP
              29         0.00     42.73      2564      45.2        75       9.2      0.20      0.53
              30         0.01     28.70      1722
              31         0.02     19.35      1161      GPVU      GPVP      GPVD
              32         0.03     13.10       786 - - - - - $/MCF - - - - -
Output data   33         0.04      8.90       534      2584      3579       994
              34         0.05      6.07       364
              35         0.06      4.15       249     GPVUL     GPVPL     GPVDL
              36         0.07      2.85       171 - - - - - $/LOG - - - - -
              37         0.08      1.97       118    116.90    161.88     44.98
              38         0.09      1.36        82
```

Figure 3—An example of an abbreviated spreadsheet for saw logs. Letters and numbers refer to the columns and rows in the spreadsheet.

Tree descriptions.—The tree descriptions are contained in cells C3 to H3. Users must get this information from yield tables such as DFSIM (Curtis and others 1982). The specific information in each cell is:

C3 = HEIGHT2, height at time of harvest;
D3 = DBH2, diameter at time of harvest;
E3 = HEIGHT1, height at time of pruning;
F3 = DBH1, diameter at time of pruning;
G3 = AGE1, age at time of pruning; and
H3 = AGE2, age at time of harvest.

Log-diameter computations.—Cells A5 to E5 are the large and small diameters of the butt 17-foot log at time of pruning (LD1, SD1) and at time of harvest (LD2, SD2). The information entered under the tree descriptions is used by the program in computing these diameters. Cubic-foot log volumes and the percentage of clear wood are estimated from these dimensions. Details of these computations will be discussed later. The specific information in each cell is:

A5 = SD2, small-end diameter of the butt log at time of harvest;
B5 = LD2, large-end diameter of the butt log at time of harvest;
D5 = SD1, small-end diameter of the butt log at time of pruning;
E5 = LD1, large-end diameter of the butt log at time of pruning.

Number of trees and success.—An estimate of the number of trees to be pruned and the proportion surviving to age of harvest must be made by the user. The specific information in the cells is:

G5 = TREES, the number of pruned trees per acre;
H5 = SUCCESS, the proportion of pruned trees assumed to be present at the time of harvest.

Lumber prices.—Users must supply the lumber prices (dollars per thousand board feet lumber tally) for the following lumber grade groups:

A7 = PRSEL, price for D select and better;
B7 = PRSS, price for select structural;
C7 = PRSTD, price for standard and better; and
D7 = PRUE, price for utility and economy.

Run identifier.—Cells E7, F7, and G7 contain information not used by the program but included to help identify the run:

E7 = SITE, King's (1966) 50-year site index.
F7 = PCT, the number of trees planted in an unthinned plantation or the number of trees remaining after precommercial thinning.
G7 = DFSIM, the page number in Curtis and others (1982) from which the tree descriptions used in this report are taken.

Tax information.—Cell H7 contains a tax adjustment factor. It is computed by subtracting the tax rate on income from the sale of lumber products from 1.0. This value will be used to convert an increase in gross product value resulting from pruning to an increase in gross product value that is net of income taxes. Use of 1.0 gives an analysis before taxes or when taxes are not relevant.

The financial output generated by PRUNE-SIM is shown in lines 27-38. Columns B and C show the present value per tree and per acre at the interest rate shown in column A. The equation used to calculate present value is:

$$\text{Present value} = \frac{\text{value pruned} - \text{value unpruned}}{(1+i)^n};$$

where:
value pruned is the value of the product from a pruned log, value unpruned is the value of the product from an unpruned log, i is the interest rate, expressed as a decimal, and n is the number of years between pruning and harvest.

These values are net of income taxes if a tax multiplier other than 1.0 is input in cell H7. The other information comes from intermediate calculations and is summarized here:
D29 = LOGVOL, volume of the butt log at time of harvest;
E29 = PCCLR, percent of the log that is clear wood;
F29 = LRF (lumber-recovery factor), board feet of lumber tally per cubic foot of log;
G29 = PSELU, proportion of lumber in the select grade from the unpruned log;
H29 = PSELP, proportion of lumber in the select grade from the pruned log.
The remaining cells show the gross product value per MCF (thousand cubic feet) and per log for unpruned and pruned logs (GPVU, GPVP, GPVUL, GPVPL) and the difference in gross product value per MCF and per log that results from pruning (GPVD, GPVDL).

2. Intermediate Calculations

Figure 4 shows the unabridged form of the spreadsheet for the example shown in figure 2. It is divided into two sections; 1-7 and 1A-7A. The documentation in 1A-7A lists the equations used for the calculations in 1-7. A detailed description of all calculations follows.

Most of section 1 is input data and was described earlier. As the documentation in section 1A-7A indicates, the calculations for log diameters (SD1, LD1, SD2, and LD2) are performed in another portion of the spreadsheet and will be discussed later.

In section 2, the cubic volume of the log at harvest (LOGVOL) is calculated by Bruce's butt-log formula (Bruce 1982). The percentage of clear volume (PCCLR) is calculated as the difference between the volume of the log at harvest and the volume at the time of pruning plus 1 inch of radial growth to allow for "healover" of the pruned branches.

In section 3, the lumber-recovery factor (LRF) and the proportion of lumber from unpruned logs that falls into each of the lumber grade groups (PSELU, PSSU, PSTDU, and PUEU) are estimated from the equations shown in section 3A. The equations for the proportion of select (PSELU) and select structural (PSSU) are conditioned to be never less than zero.

```
Section          PRUNING RECOVERY - LUMBER                           51   05-Feb
           LENGTH    STUMP  HEIGHT2     DBH2  HEIGHT1     DBH1     AGE1     AGE2
               17        1      153     25.5       53     10.4       20       60
              SD2      LD2                SD1      LD1               TREES  SUCCESS
   1         20.4     26.5                7.5     12.6                  60     0.95
            PRSEL     PRSS    PRSTD     PRUE     SITE      PCT    DFSIM      TAX
              542      250      191      111      145      300      175        1
        ------------------------------------------------------------------------
   2       LOGVOL       PERCENT CLEAR VOLUME (PCCLR)
             45.2       75
        ------------------------------------------------------------------------
                    PROPORTION OF LUMBER (UNPRUNED LOGS)
   3          LRF    PSELU     PSSU    PSTDU     PUEU
              9.2     0.20     0.47     0.25     0.08
        ------------------------------------------------------------------------
   4          LRF      PROPORTION SELECTS FROM PRUNED LOGS (PSELP)
              9.2     0.53
        ------------------------------------------------------------------------
        GROSS PRODUCT VALUE ($/MCF)
   5         GPVU     GPVP     GPVD
             2584     3579      994
        ------------------------------------------------------------------------
        GROSS PRODUCT VALUE ($/LOG)
   6        GPVUL    GPVPL    GPVDL
           116.90   161.88    44.98
        ------------------------------------------------------------------------
                     PRESENT VALUE (PVTREE and PVACRE)
             RATE     TREE     ACRE   LOGVOL    PCCLR      LRF    PSELU    PSELP
             0.00    42.73  2563.92     45.2       75      9.2     0.20     0.53
             0.01    28.70  1722.07
             0.02    19.35  1161.18     GPVU     GPVP     GPVD
   7         0.03    13.10   785.99  - - - - - $/MCF - - - - -
             0.04     8.90   534.04     2584     3579      994
             0.05     6.07   364.19
             0.06     4.15   249.27    GPVUL    GPVPL    GPVDL
             0.07     2.85   171.22  - - - - - $/LOG - - - - -
             0.08     1.97   118.02   116.90   161.88    44.98
             0.09     1.36    81.63
             0.10     0.94    56.65
        ------------------------------------------------------------------------
  1A    SD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATED AT Q1..V11
        LD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATEC AT Q1..V11
        ------------------------------------------------------------------------
        LOGVOL=0.005454*LENGTH*(0.75*SD2^2+0.25*LD2^2)
  2A    PCCLR=(1-(0.005454*LENGTH*(0.75*(SD1+2)^2+0.25*(LD1+2)^2)/
              LOGVOL))*100
        ------------------------------------------------------------------------
        LRF=8.94-31.56/SD2+3.03*(SD2^2/(LD2)^2)
  3A    PSELU=@IF(PSELU>=0,.3599-3.3145/SD2,0)
        PSSU=@IF(PSSU>=0,.6808-.0103*SD2,0)
        PSTDU=.250
        PUEU=1-PSELU-PSSU-PSTDU
        ------------------------------------------------------------------------
  4A    PSELP=@IF(PSELP>=0,(-2.64+0.1*PCCLR)/LRF,0)
        ------------------------------------------------------------------------
        GPVU=(PSELU*PRSEL+PSSU*PRSS+PSTDU*PRSTD+PUEU*PRUE)*LRF
  5A    GPVP=(PSELP*PRSEL+((1-PSELP)/(1-PSELU))*(PSSU*PRSS+PSTDU*PRSTD+PUEU*
             PRUE))*LRF
        GPVD=GPVP-GPVU
        ------------------------------------------------------------------------
        GPVUL=GPVU*LOGVOL/1000
  6A    GPVPL=GPVP*LOGVOL/1000
        GPVDL=GPVPL-GPVUL
        ------------------------------------------------------------------------
  7A    PVTREE=GPVDL/(1+RATE)^(AGE2-AGE1)*TAX*SUCCESS
        PVACRE=PVTREE*TREES
        ------------------------------------------------------------------------
        ------------------------------------------------------------------------
```

Figure 4—Spreadsheet example for saw logs. Sections 1-7 contain various outputs from the program; sections 1A-7A, the equations used to make the calculations.

In section 4, the lumber-recovery factor (LRF) is simply repeated. The lumber recovery is the same for pruned and unpruned logs. The proportion of select lumber from pruned logs (PSELP) is computed from the equation shown in section 4A. This equation is conditioned to be never less than zero.

In section 5, the gross product value per MCF of log volume is calculated for unpruned (GPVU) and pruned logs (GPVP) from the proportions of lumber grades, the lumber-recovery factor, and the prices for each grade.

The difference in value (GPVD) is the increase in value resulting from pruning. Increased volume of selects from pruned logs comes from a proportionate reduction of volume in the lower grades. The proportion of volume in the lower grades for pruned logs is calculated by use of the factor (1-PSELP)/(1-PSELU) and the proportions of lower grades for pruned logs.

In section 6, the value for pruned and unpruned logs (GPVPL and GPVUL) and the difference in value (GPVDL) is expressed in dollars per log.

In section 7, the present values per tree (PVTREE) and per acre (PVACRE) are calculated from the equations in section 7A. The other values are repeated from previous sections of the spreadsheet.

3. Veneer Analysis

Figure 5 shows in unabridged form the portion of the spreadsheet for the analysis of pruning for veneer; it is similar to the section for lumber. The PRUNE-SIM spreadsheet is designed so that when data are entered in the lumber section, everything common to both lumber and veneer is automatically copied into the veneer input section. Users should enter all the common input data in the lumber portion of the spreadsheet even if only a veneer analysis is desired. A detailed description of the calculations that are different follows.

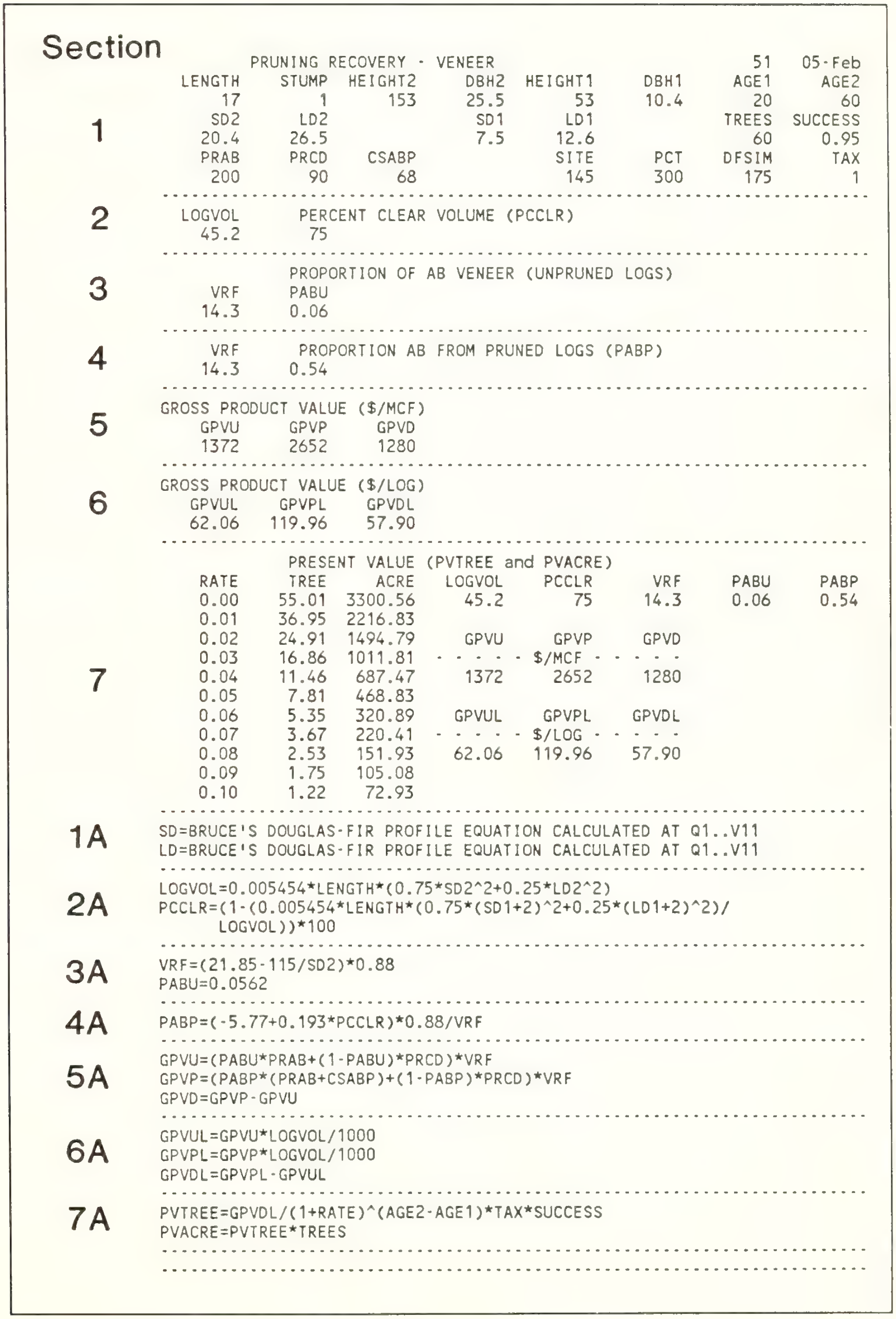
There are two differences in section 1. One difference is that prices for veneer grades AB and CD (PRAB and PRCD) are substituted for lumber prices. Prices are for green veneer and are quoted per thousand square feet on a finished panel size. All veneer prices used in this program should be converted to a 3/8-inch basis.

The second difference is that there is a cost saving (CSABP) that applies only to production of AB veneer from pruned logs. The basis for that cost saving is discussed later.

Section 2 is identical to section 2 for lumber.

In section 3, the veneer-recovery factor (VRF) and the proportion of AB veneer from the unpruned log (PABU) is computed from the equations shown in section 3A. Veneer recovery is based on dry trimmed veneer.

In section 4, the veneer-recovery factor is repeated. The veneer recovery is the same for pruned and unpruned logs. The proportion of AB veneer from pruned logs (PABP) is computed from the equation shown in section 4A.



```
Section
              PRUNING RECOVERY - VENEER                                  51    05-Feb
        LENGTH     STUMP  HEIGHT2     DBH2  HEIGHT1      DBH1      AGE1      AGE2
            17         1      153     25.5       53      10.4        20        60
  1        SD2       LD2               SD1      LD1               TREES   SUCCESS
          20.4      26.5               7.5     12.6                  60      0.95
          PRAB      PRCD    CSABP              SITE       PCT     DFSIM       TAX
           200        90       68               145       300       175         1
      ---------------------------------------------------------------------------
  2     LOGVOL       PERCENT CLEAR VOLUME (PCCLR)
          45.2        75
      ---------------------------------------------------------------------------
                    PROPORTION OF AB VENEER (UNPRUNED LOGS)
  3        VRF      PABU
          14.3      0.06
      ---------------------------------------------------------------------------
  4        VRF       PROPORTION AB FROM PRUNED LOGS (PABP)
          14.3      0.54
      ---------------------------------------------------------------------------
      GROSS PRODUCT VALUE ($/MCF)
  5       GPVU      GPVP      GPVD
          1372      2652      1280
      ---------------------------------------------------------------------------
      GROSS PRODUCT VALUE ($/LOG)
  6      GPVUL     GPVPL     GPVDL
         62.06    119.96     57.90
      ---------------------------------------------------------------------------
                    PRESENT VALUE (PVTREE and PVACRE)
          RATE      TREE     ACRE   LOGVOL     PCCLR       VRF      PABU      PABP
          0.00     55.01  3300.56     45.2        75      14.3      0.06      0.54
          0.01     36.95  2216.83
          0.02     24.91  1494.79     GPVU      GPVP      GPVD
          0.03     16.86  1011.81   - - - - - $/MCF - - - - -
  7       0.04     11.46   687.47     1372      2652      1280
          0.05      7.81   468.83
          0.06      5.35   320.89    GPVUL     GPVPL     GPVDL
          0.07      3.67   220.41   - - - - - $/LOG - - - - -
          0.08      2.53   151.93    62.06    119.96     57.90
          0.09      1.75   105.08
          0.10      1.22    72.93
      ---------------------------------------------------------------------------
 1A   SD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATED AT Q1..V11
      LD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATED AT Q1..V11
      ---------------------------------------------------------------------------
      LOGVOL=0.005454*LENGTH*(0.75*SD2^2+0.25*LD2^2)
 2A   PCCLR=(1-(0.005454*LENGTH*(0.75*(SD1+2)^2+0.25*(LD1+2)^2)/
            LOGVOL))*100
      ---------------------------------------------------------------------------
 3A   VRF=(21.85-115/SD2)*0.88
      PABU=0.0562
      ---------------------------------------------------------------------------
 4A   PABP=(-5.77+0.193*PCCLR)*0.88/VRF
      ---------------------------------------------------------------------------
      GPVU=(PABU*PRAB+(1-PABU)*PRCD)*VRF
 5A   GPVP=(PABP*(PRAB+CSABP)+(1-PABP)*PRCD)*VRF
      GPVD=GPVP-GPVU
      ---------------------------------------------------------------------------
      GPVUL=GPVU*LOGVOL/1000
 6A   GPVPL=GPVP*LOGVOL/1000
      GPVDL=GPVPL-GPVUL
      ---------------------------------------------------------------------------
 7A   PVTREE=GPVDL/(1+RATE)^(AGE2-AGE1)*TAX*SUCCESS
      PVACRE=PVTREE*TREES
      ---------------------------------------------------------------------------
      ---------------------------------------------------------------------------
```

Figure 5—Spreadsheet example for veneer logs. Sections 1-7 contain various outputs from the program; sections 1A-7A, the equations used to make the calculations.

In section 5, the gross product value per MCF of log volume is computed for unpruned (GPVU) and pruned logs (GPVP). Value is computed by use of the proportion of veneer by grade, price for each grade, the cost saving for AB veneer from pruned logs, and the veneer-recovery factor. The increase in value resulting from pruning is the difference in value between pruned and unpruned logs (GPVD).

Section 6 is comparable to section 6 for lumber.

Section 7 is comparable to section 7 for lumber except that veneer-recovery factor (VRF) replaces lumber-recovery factor (LRF) and the proportion of AB veneer (PABU and PABP) replaces the proportion of select lumber (PSELU and PSELP).

4. Log Diameters

Figure 6 shows the section of the spreadsheet that contains the equations needed to compute the diameters of the 17-foot butt log. A tree profile equation that predicts diameters inside bark at any point on the stem was used.[1] A similar set of equations is described by Bruce (1984). The independent variables needed to make diameter predictions are DBH and total height, both at the time of pruning (cells E3 and F3 in fig. 3) and at the time of harvest (cells C3 and D3 in fig. 3). A description of how the calculations are made follows.

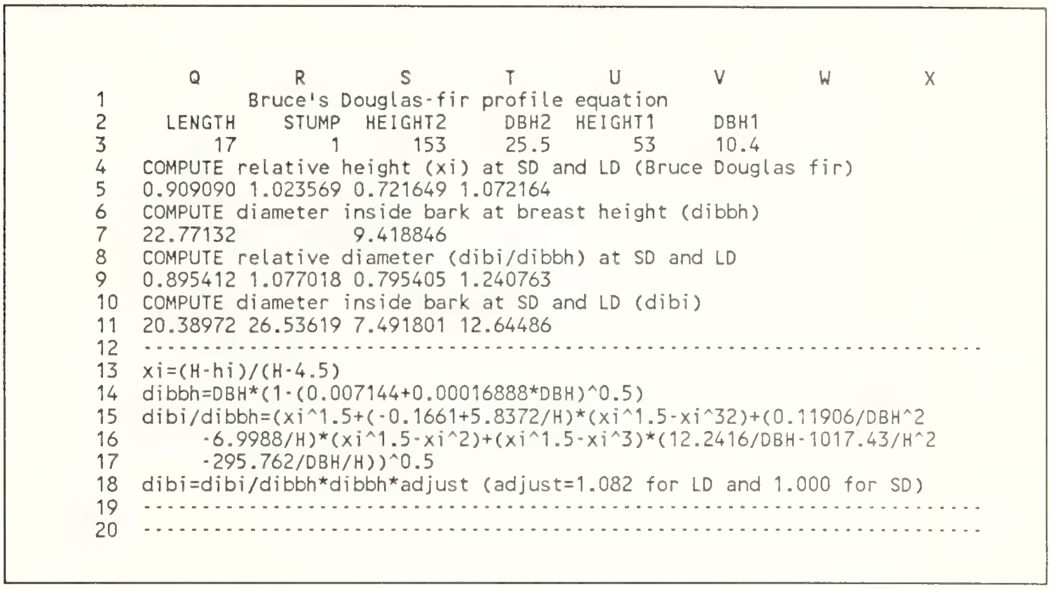
Line 5 shows four relative heights: (1) the small end of the butt log at harvest, (2) the large end of the butt log at harvest, (3) the small end of the butt log at time of pruning, and (4) the large end of the butt log at time of pruning. These heights are calculated from the equation in line 13 where:
xi = relative height;
H = height of the tree; and
hi = height at which relative height is being computed.

Line 7 shows the diameter inside bark at breast height for the tree at harvest and at time of pruning. These diameters are calculated from the equation in line 14, where:
dibbh = diameter inside bark at breast height, and
DBH = diameter outside bark at breast height.

Line 9 shows four relative diameters corresponding to the relative heights computed in line 5. These calculations use the equation in lines 15-17, where:
dibi = diameter inside bark at height "i,"
dibi/dibbh = relative diameter, and other variables are as defined above.

---

[1] Unpublished data on file with D. Bruce, mensurationist, USDA Forest Service, Forestry Sciences Laboratory, P.O. Box 3890, Portland, OR 97208.



```
        Q         R         S         T         U         V         W         X
 1              Bruce's Douglas-fir profile equation
 2        LENGTH    STUMP  HEIGHT2    DBH2  HEIGHT1     DBH1
 3            17        1      153    25.5       53     10.4
 4    COMPUTE relative height (xi) at SD and LD (Bruce Douglas fir)
 5    0.909090 1.023569 0.721649 1.072164
 6    COMPUTE diameter inside bark at breast height (dibbh)
 7    22.77132          9.418846
 8    COMPUTE relative diameter (dibi/dibbh) at SD and LD
 9    0.895412 1.077018 0.795405 1.240763
10    COMPUTE diameter inside bark at SD and LD (dibi)
11    20.38972 26.53619 7.491801 12.64486
12    -----------------------------------------------------------------------
13    xi=(H-hi)/(H-4.5)
14    dibbh=DBH*(1-(0.007144+0.00016888*DBH)^0.5)
15    dibi/dibbh=(xi^1.5+(-0.1661+5.8372/H)*(xi^1.5-xi^32)+(0.11906/DBH^2
16         -6.9988/H)*(xi^1.5-xi^2)+(xi^1.5-xi^3)*(12.2416/DBH-1017.43/H^2
17         -295.762/DBH/H))^0.5
18    dibi=dibi/dibbh*dibbh*adjust (adjust=1.082 for LD and 1.000 for SD)
19    -----------------------------------------------------------------------
20    -----------------------------------------------------------------------
```

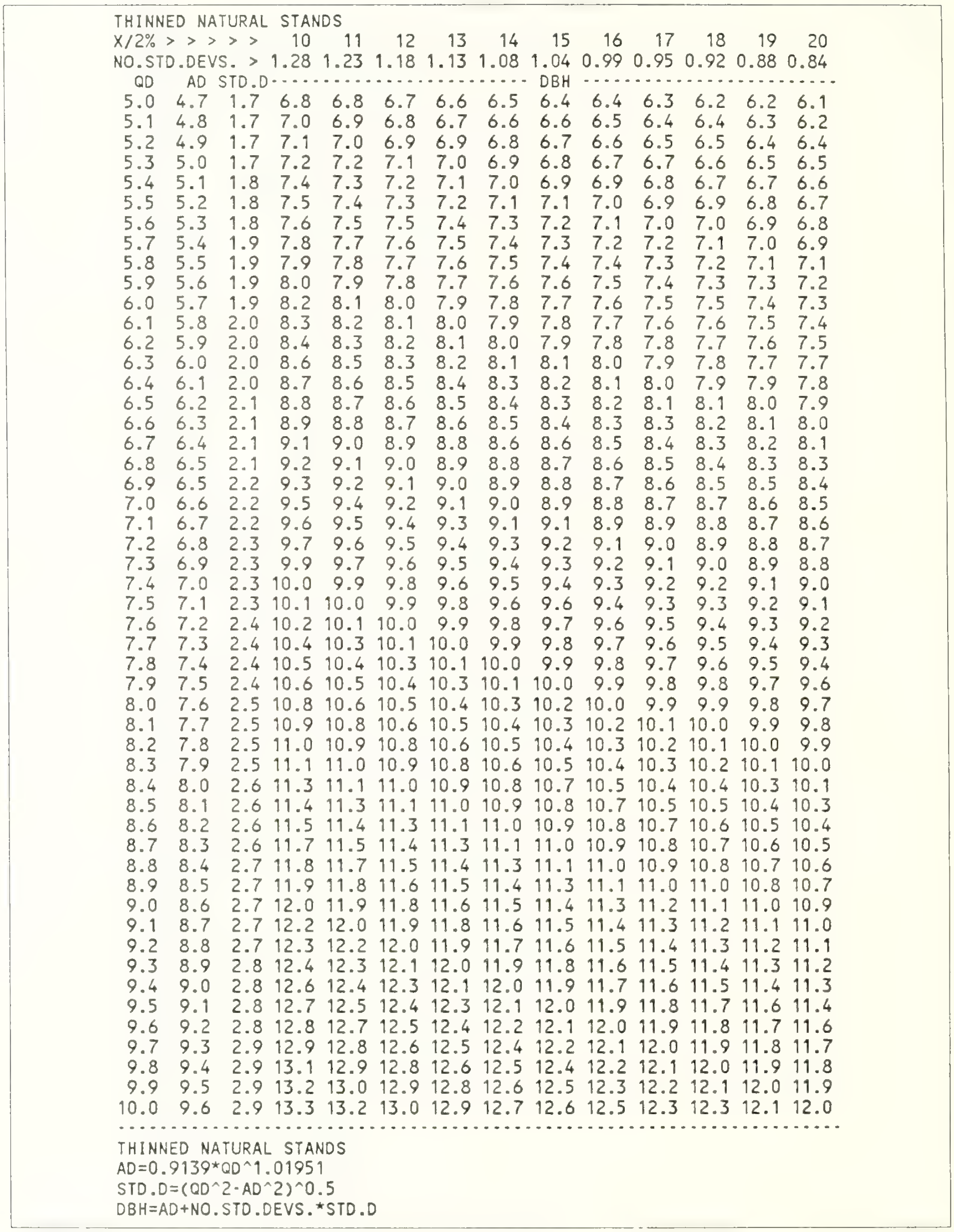
Figure 6—Portion of the spreadsheet where log diameters are calculated. Letters and numbers refer to columns and rows in the spreadsheet.

Line 11 shows the four inside bark diameters needed by the PRUNE-SIM spreadsheet; the diameter of the small end of the butt log at harvest, the large end of the butt log at harvest, the small end of the butt log at time of pruning, and the large end of the butt log at time of pruning. These are calculated from the equation in line 18 where: “adjust” is as shown, and other variables are as defined above.

Adjust is a factor applied to the large-end diameter of the butt log. The data used by Bruce (see footnote 1) to develop the profile equation included very few measurements at 1-foot—the height of the large end of the butt log in our analysis. When we compared diameter estimates made by Bruce's equation with actual 1-foot diameters from two independent data sets, we found that the Bruce equation consistently underestimated values; an average adjustment of 1.082 was calculated with the data used to develop the recovery equations for the pruning model.

5. Average Diameter of Pruned Trees

One problem in deciding what tree descriptions are appropriate to represent pruned and unpruned trees is estimating the average DBH of the pruned trees. Dominants or codominants are the most likely candidates for pruning; thus, the average size of pruned trees will be greater than the average stand diameter given in growth and yield models. Our assumption is that pruned trees are the n largest trees in the stand, where n is the number of pruned trees. Figure 7 is a spreadsheet called STDDEV2 that is used to estimate the median diameter of the n largest trees in a stand. We have assumed that the tree diameters are normally distributed. This spreadsheet will be included with all copies of PRUNE-SIM. An example of how to use STDDEV2 follows.



```
THINNED NATURAL STANDS
X/2% > > > > >    10    11    12    13    14    15    16    17    18    19    20
NO.STD.DEVS. >  1.28  1.23  1.18  1.13  1.08  1.04  0.99  0.95  0.92  0.88  0.84
  QD    AD STD.D------------------------- DBH -------------------------
  5.0   4.7  1.7   6.8   6.8   6.7   6.6   6.5   6.4   6.4   6.3   6.2   6.2   6.1
  5.1   4.8  1.7   7.0   6.9   6.8   6.7   6.6   6.6   6.5   6.4   6.4   6.3   6.2
  5.2   4.9  1.7   7.1   7.0   6.9   6.9   6.8   6.7   6.6   6.5   6.5   6.4   6.4
  5.3   5.0  1.7   7.2   7.2   7.1   7.0   6.9   6.8   6.7   6.7   6.6   6.5   6.5
  5.4   5.1  1.8   7.4   7.3   7.2   7.1   7.0   6.9   6.9   6.8   6.7   6.7   6.6
  5.5   5.2  1.8   7.5   7.4   7.3   7.2   7.1   7.1   7.0   6.9   6.9   6.8   6.7
  5.6   5.3  1.8   7.6   7.5   7.5   7.4   7.3   7.2   7.1   7.0   7.0   6.9   6.8
  5.7   5.4  1.9   7.8   7.7   7.6   7.5   7.4   7.3   7.2   7.2   7.1   7.0   6.9
  5.8   5.5  1.9   7.9   7.8   7.7   7.6   7.5   7.4   7.4   7.3   7.2   7.1   7.1
  5.9   5.6  1.9   8.0   7.9   7.8   7.7   7.6   7.6   7.5   7.4   7.3   7.3   7.2
  6.0   5.7  1.9   8.2   8.1   8.0   7.9   7.8   7.7   7.6   7.5   7.5   7.4   7.3
  6.1   5.8  2.0   8.3   8.2   8.1   8.0   7.9   7.8   7.7   7.6   7.6   7.5   7.4
  6.2   5.9  2.0   8.4   8.3   8.2   8.1   8.0   7.9   7.8   7.8   7.7   7.6   7.5
  6.3   6.0  2.0   8.6   8.5   8.3   8.2   8.1   8.1   8.0   7.9   7.8   7.7   7.7
  6.4   6.1  2.0   8.7   8.6   8.5   8.4   8.3   8.2   8.1   8.0   7.9   7.9   7.8
  6.5   6.2  2.1   8.8   8.7   8.6   8.5   8.4   8.3   8.2   8.1   8.1   8.0   7.9
  6.6   6.3  2.1   8.9   8.8   8.7   8.6   8.5   8.4   8.3   8.3   8.2   8.1   8.0
  6.7   6.4  2.1   9.1   9.0   8.9   8.8   8.6   8.6   8.5   8.4   8.3   8.2   8.1
  6.8   6.5  2.1   9.2   9.1   9.0   8.9   8.8   8.7   8.6   8.5   8.4   8.3   8.3
  6.9   6.5  2.2   9.3   9.2   9.1   9.0   8.9   8.8   8.7   8.6   8.5   8.5   8.4
  7.0   6.6  2.2   9.5   9.4   9.2   9.1   9.0   8.9   8.8   8.7   8.7   8.6   8.5
  7.1   6.7  2.2   9.6   9.5   9.4   9.3   9.1   9.1   8.9   8.9   8.8   8.7   8.6
  7.2   6.8  2.3   9.7   9.6   9.5   9.4   9.3   9.2   9.1   9.0   8.9   8.8   8.7
  7.3   6.9  2.3   9.9   9.7   9.6   9.5   9.4   9.3   9.2   9.1   9.0   8.9   8.8
  7.4   7.0  2.3  10.0   9.9   9.8   9.6   9.5   9.4   9.3   9.2   9.2   9.1   9.0
  7.5   7.1  2.3  10.1  10.0   9.9   9.8   9.6   9.6   9.4   9.3   9.3   9.2   9.1
  7.6   7.2  2.4  10.2  10.1  10.0   9.9   9.8   9.7   9.6   9.5   9.4   9.3   9.2
  7.7   7.3  2.4  10.4  10.3  10.1  10.0   9.9   9.8   9.7   9.6   9.5   9.4   9.3
  7.8   7.4  2.4  10.5  10.4  10.3  10.1  10.0   9.9   9.8   9.7   9.6   9.5   9.4
  7.9   7.5  2.4  10.6  10.5  10.4  10.3  10.1  10.0   9.9   9.8   9.8   9.7   9.6
  8.0   7.6  2.5  10.8  10.6  10.5  10.4  10.3  10.2  10.0   9.9   9.9   9.8   9.7
  8.1   7.7  2.5  10.9  10.8  10.6  10.5  10.4  10.3  10.2  10.1  10.0   9.9   9.8
  8.2   7.8  2.5  11.0  10.9  10.8  10.6  10.5  10.4  10.3  10.2  10.1  10.0   9.9
  8.3   7.9  2.5  11.1  11.0  10.9  10.8  10.6  10.5  10.4  10.3  10.2  10.1  10.0
  8.4   8.0  2.6  11.3  11.1  11.0  10.9  10.8  10.7  10.5  10.4  10.4  10.3  10.1
  8.5   8.1  2.6  11.4  11.3  11.1  11.0  10.9  10.8  10.7  10.5  10.5  10.4  10.3
  8.6   8.2  2.6  11.5  11.4  11.3  11.1  11.0  10.9  10.8  10.7  10.6  10.5  10.4
  8.7   8.3  2.6  11.7  11.5  11.4  11.3  11.1  11.0  10.9  10.8  10.7  10.6  10.5
  8.8   8.4  2.7  11.8  11.7  11.5  11.4  11.3  11.1  11.0  10.9  10.8  10.7  10.6
  8.9   8.5  2.7  11.9  11.8  11.6  11.5  11.4  11.3  11.1  11.0  11.0  10.8  10.7
  9.0   8.6  2.7  12.0  11.9  11.8  11.6  11.5  11.4  11.3  11.2  11.1  11.0  10.9
  9.1   8.7  2.7  12.2  12.0  11.9  11.8  11.6  11.5  11.4  11.3  11.2  11.1  11.0
  9.2   8.8  2.7  12.3  12.2  12.0  11.9  11.7  11.6  11.5  11.4  11.3  11.2  11.1
  9.3   8.9  2.8  12.4  12.3  12.1  12.0  11.9  11.8  11.6  11.5  11.4  11.3  11.2
  9.4   9.0  2.8  12.6  12.4  12.3  12.1  12.0  11.9  11.7  11.6  11.5  11.4  11.3
  9.5   9.1  2.8  12.7  12.5  12.4  12.3  12.1  12.0  11.9  11.8  11.7  11.6  11.4
  9.6   9.2  2.8  12.8  12.7  12.5  12.4  12.2  12.1  12.0  11.9  11.8  11.7  11.6
  9.7   9.3  2.9  12.9  12.8  12.6  12.5  12.4  12.2  12.1  12.0  11.9  11.8  11.7
  9.8   9.4  2.9  13.1  12.9  12.8  12.6  12.5  12.4  12.2  12.1  12.0  11.9  11.8
  9.9   9.5  2.9  13.2  13.0  12.9  12.8  12.6  12.5  12.3  12.2  12.1  12.0  11.9
 10.0   9.6  2.9  13.3  13.2  13.0  12.9  12.7  12.6  12.5  12.3  12.3  12.1  12.0
------------------------------------------------------------------------------------
THINNED NATURAL STANDS
AD=0.9139*QD^1.01951
STD.D=(QD^2-AD^2)^0.5
DBH=AD+NO.STD.DEVS.*STD.D
```

Figure 7—Spreadsheet STDDEV2 used to calculate the median diameter of the pruned trees.

```
UNTHINNED PLANTATIONS
X/2% > > > > >    10    11    12    13    14    15    16    17    18    19    20
NO.STD.DEVS. > 1.28  1.23  1.18  1.13  1.08  1.04  0.99  0.95  0.92  0.88  0.84
  QD    AD  STD.D------------------------ DBH -----------------------------
  5.0  4.7  1.7  6.8   6.8   6.7   6.6   6.5   6.4   6.4   6.3   6.2   6.2   6.1
  5.1  4.8  1.7  7.0   6.9   6.8   6.7   6.6   6.6   6.5   6.4   6.4   6.3   6.2
  5.2  4.9  1.7  7.1   7.0   6.9   6.8   6.8   6.7   6.6   6.5   6.5   6.4   6.3
  5.3  5.0  1.7  7.2   7.1   7.0   7.0   6.9   6.8   6.7   6.6   6.6   6.5   6.5
  5.4  5.1  1.7  7.3   7.3   7.2   7.1   7.0   6.9   6.8   6.8   6.7   6.6   6.6
  5.5  5.2  1.8  7.5   7.4   7.3   7.2   7.1   7.0   7.0   6.9   6.8   6.8   6.7
  5.6  5.3  1.8  7.6   7.5   7.4   7.3   7.2   7.2   7.1   7.0   6.9   6.9   6.8
  5.7  5.4  1.8  7.7   7.6   7.5   7.4   7.4   7.3   7.2   7.1   7.1   7.0   6.9
  5.8  5.5  1.8  7.8   7.7   7.7   7.6   7.5   7.4   7.3   7.2   7.2   7.1   7.0
  5.9  5.6  1.8  8.0   7.9   7.8   7.7   7.6   7.5   7.4   7.4   7.3   7.2   7.2
  6.0  5.7  1.9  8.1   8.0   7.9   7.8   7.7   7.6   7.5   7.5   7.4   7.3   7.3
  6.1  5.8  1.9  8.2   8.1   8.0   7.9   7.8   7.8   7.7   7.6   7.5   7.5   7.4
  6.2  5.9  1.9  8.3   8.2   8.1   8.0   8.0   7.9   7.8   7.7   7.6   7.6   7.5
  6.3  6.0  1.9  8.5   8.4   8.3   8.2   8.1   8.0   7.9   7.8   7.8   7.7   7.6
  6.4  6.1  1.9  8.6   8.5   8.4   8.3   8.2   8.1   8.0   7.9   7.9   7.8   7.7
  6.5  6.2  2.0  8.7   8.6   8.5   8.4   8.3   8.2   8.1   8.1   8.0   7.9   7.8
  6.6  6.3  2.0  8.8   8.7   8.6   8.5   8.4   8.3   8.3   8.2   8.1   8.0   8.0
  6.7  6.4  2.0  8.9   8.8   8.7   8.6   8.5   8.5   8.4   8.3   8.2   8.1   8.1
  6.8  6.5  2.0  9.1   9.0   8.9   8.8   8.7   8.6   8.5   8.4   8.3   8.3   8.2
  6.9  6.6  2.0  9.2   9.1   9.0   8.9   8.8   8.7   8.6   8.5   8.5   8.4   8.3
  7.0  6.7  2.0  9.3   9.2   9.1   9.0   8.9   8.8   8.7   8.6   8.6   8.5   8.4
  7.1  6.8  2.1  9.4   9.3   9.2   9.1   9.0   8.9   8.8   8.7   8.7   8.6   8.5
  7.2  6.9  2.1  9.5   9.4   9.3   9.2   9.1   9.0   8.9   8.9   8.8   8.7   8.6
  7.3  7.0  2.1  9.7   9.6   9.5   9.4   9.2   9.2   9.1   9.0   8.9   8.8   8.7
  7.4  7.1  2.1  9.8   9.7   9.6   9.5   9.4   9.3   9.2   9.1   9.0   8.9   8.9
  7.5  7.2  2.1  9.9   9.8   9.7   9.6   9.5   9.4   9.3   9.2   9.1   9.1   9.0
  7.6  7.3  2.1 10.0   9.9   9.8   9.7   9.6   9.5   9.4   9.3   9.3   9.2   9.1
  7.7  7.4  2.1 10.1  10.0   9.9   9.8   9.7   9.6   9.5   9.4   9.4   9.3   9.2
  7.8  7.5  2.2 10.3  10.1  10.0   9.9   9.8   9.7   9.6   9.5   9.5   9.4   9.3
  7.9  7.6  2.2 10.4  10.3  10.2  10.0   9.9   9.9   9.7   9.7   9.6   9.5   9.4
  8.0  7.7  2.2 10.5  10.4  10.3  10.2  10.1  10.0   9.9   9.8   9.7   9.6   9.5
  8.1  7.8  2.2 10.6  10.5  10.4  10.3  10.2  10.1  10.0   9.9   9.8   9.7   9.6
  8.2  7.9  2.2 10.7  10.6  10.5  10.4  10.3  10.2  10.1  10.0   9.9   9.8   9.8
  8.3  8.0  2.2 10.8  10.7  10.6  10.5  10.4  10.3  10.2  10.1  10.0  10.0   9.9
  8.4  8.1  2.2 11.0  10.8  10.7  10.6  10.5  10.4  10.3  10.2  10.2  10.1  10.0
  8.5  8.2  2.2 11.1  11.0  10.8  10.7  10.6  10.5  10.4  10.3  10.3  10.2  10.1
  8.6  8.3  2.3 11.2  11.1  11.0  10.9  10.7  10.6  10.5  10.4  10.4  10.3  10.2
  8.7  8.4  2.3 11.3  11.2  11.1  11.0  10.9  10.8  10.6  10.6  10.5  10.4  10.3
  8.8  8.5  2.3 11.4  11.3  11.2  11.1  11.0  10.9  10.8  10.7  10.6  10.5  10.4
  8.9  8.6  2.3 11.5  11.4  11.3  11.2  11.1  11.0  10.9  10.8  10.7  10.6  10.5
  9.0  8.7  2.3 11.6  11.5  11.4  11.3  11.2  11.1  11.0  10.9  10.8  10.7  10 6
  9.1  8.8  2.3 11.8  11.6  11.5  11.4  11.3  11.2  11.1  11.0  10.9  10.8  10.7
  9.2  8.9  2.3 11.9  11.8  11.6  11.5  11.4  11.3  11.2  11.1  11.0  10.9  10.9
  9.3  9.0  2.3 12.0  11.9  11.8  11.6  11.5  11.4  11.3  11.2  11.1  11.1  11.0
  9.4  9.1  2.3 12.1  12.0  11.9  11.8  11.6  11.5  11.4  11.3  11.3  11.2  11.1
  9.5  9.2  2.4 12.2  12.1  12.0  11.9  11.7  11.6  11.5  11.4  11.4  11.3  11.2
  9.6  9.3  2.4 12.3  12.2  12.1  12.0  11.9  11.8  11.6  11.5  11.5  11.4  11.3
  9.7  9.4  2.4 12.4  12.3  12.2  12.1  12.0  11.9  11.8  11.7  11.6  11.5  11.4
  9.8  9.5  2.4 12.6  12.4  12.3  12.2  12.1  12.0  11.9  11.8  11.7  11.6  11.5
  9.9  9.6  2.4 12.7  12.5  12.4  12.3  12.2  12.1  12.0  11.9  11.8  11.7  11.6
 10.0  9.7  2.4 12.8  12.7  12.5  12.4  12.3  12.2  12.1  12.0  11.9  11.8  11.7
-----------------------------------------------------------------------------
UNTHINNED PLANTATIONS
AD=0.8826*QD^1.04143
STD.D=(QD^2-AD^2)^0.5
DBH=AD+NO.STD.DEVS.*STD.D
```

Figure 7—(continued)

```
THINNED PLANTATIONS
X/2% > > > > >      10    11    12    13    14    15    16    17    18    19    20
NO.STD.DEVS. >    1.28  1.23  1.18  1.13  1.08  1.04  0.99  0.95  0.92  0.88  0.84
  QD    AD STD.D------------------------------ DBH -----------------------------
 5.0   4.9   1.2   6.4   6.3   6.2   6.2   6.1   6.1   6.0   6.0   5.9   5.9   5.8
 5.1   5.0   1.2   6.5   6.4   6.4   6.3   6.3   6.2   6.1   6.1   6.1   6.0   6.0
 5.2   5.1   1.2   6.6   6.6   6.5   6.4   6.4   6.3   6.3   6.2   6.2   6.1   6.1
 5.3   5.2   1.2   6.7   6.7   6.6   6.6   6.5   6.4   6.4   6.3   6.3   6.2   6.2
 5.4   5.3   1.3   6.9   6.8   6.7   6.7   6.6   6.6   6.5   6.4   6.4   6.4   6.3
 5.5   5.4   1.3   7.0   6.9   6.9   6.8   6.7   6.7   6.6   6.6   6.5   6.5   6.4
 5.6   5.4   1.3   7.1   7.0   7.0   6.9   6.8   6.8   6.7   6.7   6.6   6.6   6.5
 5.7   5.5   1.3   7.2   7.2   7.1   7.0   7.0   6.9   6.8   6.8   6.8   6.7   6.6
 5.8   5.6   1.3   7.3   7.3   7.2   7.1   7.1   7.0   7.0   6.9   6.9   6.8   6.8
 5.9   5.7   1.3   7.5   7.4   7.3   7.3   7.2   7.1   7.1   7.0   7.0   6.9   6.9
 6.0   5.8   1.4   7.6   7.5   7.5   7.4   7.3   7.3   7.2   7.1   7.1   7.0   7.0
 6.1   5.9   1.4   7.7   7.6   7.6   7.5   7.4   7.4   7.3   7.3   7.2   7.2   7.1
 6.2   6.0   1.4   7.8   7.8   7.7   7.6   7.6   7.5   7.4   7.4   7.3   7.3   7.2
 6.3   6.1   1.4   8.0   7.9   7.8   7.7   7.7   7.6   7.5   7.5   7.4   7.4   7.3
 6.4   6.2   1.4   8.1   8.0   7.9   7.9   7.8   7.7   7.7   7.6   7.6   7.5   7.4
 6.5   6.3   1.5   8.2   8.1   8.1   8.0   7.9   7.9   7.8   7.7   7.7   7.6   7.6
 6.6   6.4   1.5   8.3   8.3   8.2   8.1   8.0   8.0   7.9   7.8   7.8   7.7   7.7
 6.7   6.5   1.5   8.4   8.4   8.3   8.2   8.1   8.1   8.0   8.0   7.9   7.8   7.8
 6.8   6.6   1.5   8.6   8.5   8.4   8.3   8.3   8.2   8.1   8.1   8.0   8.0   7.9
 6.9   6.7   1.5   8.7   8.6   8.5   8.5   8.4   8.3   8.2   8.2   8.1   8.1   8.0
 7.0   6.8   1.6   8.8   8.7   8.7   8.6   8.5   8.4   8.4   8.3   8.3   8.2   8.1
 7.1   6.9   1.6   8.9   8.9   8.8   8.7   8.6   8.6   8.5   8.4   8.4   8.3   8.2
 7.2   7.0   1.6   9.1   9.0   8.9   8.8   8.7   8.7   8.6   8.5   8.5   8.4   8.4
 7.3   7.1   1.6   9.2   9.1   9.0   8.9   8.9   8.8   8.7   8.6   8.6   8.5   8.5
 7.4   7.2   1.6   9.3   9.2   9.1   9.1   9.0   8.9   8.8   8.8   8.7   8.6   8.6
 7.5   7.3   1.6   9.4   9.3   9.3   9.2   9.1   9.0   8.9   8.9   8.8   8.8   8.7
 7.6   7.4   1.7   9.5   9.5   9.4   9.3   9.2   9.1   9.1   9.0   8.9   8.9   8.8
 7.7   7.5   1.7   9.7   9.6   9.5   9.4   9.3   9.3   9.2   9.1   9.1   9.0   8.9
 7.8   7.6   1.7   9.8   9.7   9.6   9.5   9.4   9.4   9.3   9.2   9.2   9.1   9.0
 7.9   7.7   1.7   9.9   9.8   9.7   9.6   9.6   9.5   9.4   9.3   9.3   9.2   9.1
 8.0   7.8   1.7  10.0   9.9   9.8   9.8   9.7   9.6   9.5   9.5   9.4   9.3   9.3
 8.1   7.9   1.7  10.1  10.1  10.0   9.9   9.8   9.7   9.6   9.6   9.5   9.4   9.4
 8.2   8.0   1.8  10.3  10.2  10.1  10.0   9.9   9.8   9.8   9.7   9.6   9.6   9.5
 8.3   8.1   1.8  10.4  10.3  10.2  10.1  10.0  10.0   9.9   9.8   9.7   9.7   9.6
 8.4   8.2   1.8  10.5  10.4  10.3  10.2  10.1  10.1  10.0   9.9   9.9   9.8   9.7
 8.5   8.3   1.8  10.6  10.5  10.4  10.3  10.3  10.2  10.1  10.0  10.0   9.9   9.8
 8.6   8.4   1.8  10.7  10.6  10.6  10.5  10.4  10.3  10.2  10.1  10.1  10.0   9.9
 8.7   8.5   1.8  10.9  10.8  10.7  10.6  10.5  10.4  10.3  10.3  10.2  10.1  10.1
 8.8   8.6   1.9  11.0  10.9  10.8  10.7  10.6  10.5  10.4  10.4  10.3  10.2  10.2
 8.9   8.7   1.9  11.1  11.0  10.9  10.8  10.7  10.7  10.6  10.5  10.4  10.4  10.3
 9.0   8.8   1.9  11.2  11.1  11.0  10.9  10.8  10.8  10.7  10.6  10.5  10.5  10.4
 9.1   8.9   1.9  11.3  11.2  11.1  11.1  11.0  10.9  10.8  10.7  10.7  10.6  10.5
 9.2   9.0   1.9  11.5  11.4  11.3  11.2  11.1  11.0  10.9  10.8  10.8  10.7  10.6
 9.3   9.1   1.9  11.6  11.5  11.4  11.3  11.2  11.1  11.0  10.9  10.9  10.8  10.7
 9.4   9.2   2.0  11.7  11.6  11.5  11.4  11.3  11.2  11.1  11.1  11.0  10.9  10.8
 9.5   9.3   2.0  11.8  11.7  11.6  11.5  11.4  11.3  11.2  11.2  11.1  11.0  11.0
 9.6   9.4   2.0  11.9  11.8  11.7  11.6  11.5  11.5  11.4  11.3  11.2  11.1  11.1
 9.7   9.5   2.0  12.1  12.0  11.9  11.8  11.7  11.6  11.5  11.4  11.3  11.3  11.2
 9.8   9.6   2.0  12.2  12.1  12.0  11.9  11.8  11.7  11.6  11.5  11.4  11.4  11.3
 9.9   9.7   2.0  12.3  12.2  12.1  12.0  11.9  11.8  11.7  11.6  11.6  11.5  11.4
10.0   9.8   2.1  12.4  12.3  12.2  12.1  12.0  11.9  11.8  11.7  11.7  11.6  11.5
---------------------------------------------------------------------------------
THINNED PLANTATIONS
AD=0.9561*QD^1.01015
STD.D=(QD^2-AD^2)^0.5
DBH=AD+NO.STD.DEVS.*STD.D
```

Figure 7—(continued)

To estimate the median diameter of pruned trees, first estimate the arithmetic mean diameter (AD) of the stand using the quadratic mean diameter (QD) given in the DFSIM output. The equations used to estimate arithmetic diameter are:

Thinned natural stands, $AD = 0.9139 * QD^{1.01951}$.
Unthinned plantations, $AD = 0.8826 * QD^{1.04143}$.
Thinned plantations, $AD = 0.9561 * QD^{1.01015}$.

These equations are based on data used to develop the DFSIM model.[2]

The next step is to estimate the standard deviation (STD.D) from the equation:

$$STD.D = (QD^2 - AD^2)^{0.5}.$$

The median diameter at breast height of the n largest trees is found by referring to a table of values for a standard normal distribution. The number of standard deviations above which n/2 percent of the population falls is the median diameter of the n largest members of the population. That number of standard deviations times the standard deviation for this stand plus the arithmetic mean diameter of this stand is the median diameter for the pruned trees. Figure 7 shows the median diameter of the pruned trees for a range of stand diameters and proportion of the stands to be pruned. For example, a precommercially thinned stand with a QD of 6.0 inches has an AD of 5.7 inches. The estimated standard deviation of that stand is 1.9. If the largest 30 percent of the trees are pruned, x/2 percent equals 15 percent. The median tree is 1.04 standard deviations above the mean: 1.04 times 1.9 is 2.0 inches above the mean of 5.7. The estimated median diameter of the pruned trees is therefore 7.7. The approach described here is not an exact solution to the problem, but it appears to be an acceptable approximation.

The DFSIM yield tables and the approach described above can now be used to provide the data needed to simulate a comparison with and without pruning. Diameter of pruned trees at the time of pruning can be determined as described above by use of the DBH (quadratic mean diameter) shown in the DFSIM yield tables. The height of the pruned trees at the time of pruning is probably best represented by "HT40" rather than "LOREY HT." HT40 is the mean height of the 40 largest trees in the stand. LOREY HT is the height of the tree of average volume. Since we have assumed that the pruned trees will be the n largest trees in the stand, the height of the 40 largest trees in the stand is probably closer than the height of the tree of average volume. Sensitivity analysis done with differences in height at time of pruning suggests that differences of the magnitude of the difference between HT40 and LOREY HT will have a minor effect on the results. If pruning regimes are set so that most or all of the trees at final harvest are pruned trees, no adjustment is needed to determine the diameter of the pruned trees. The quadratic mean diameter reported in the DFSIM tables can be used directly because the quadratic mean diameter and the arithmetic mean diameter are almost identical for trees of harvest size. At harvest, LOREY HT probably best represents the height of the pruned trees if almost all the trees are pruned trees.

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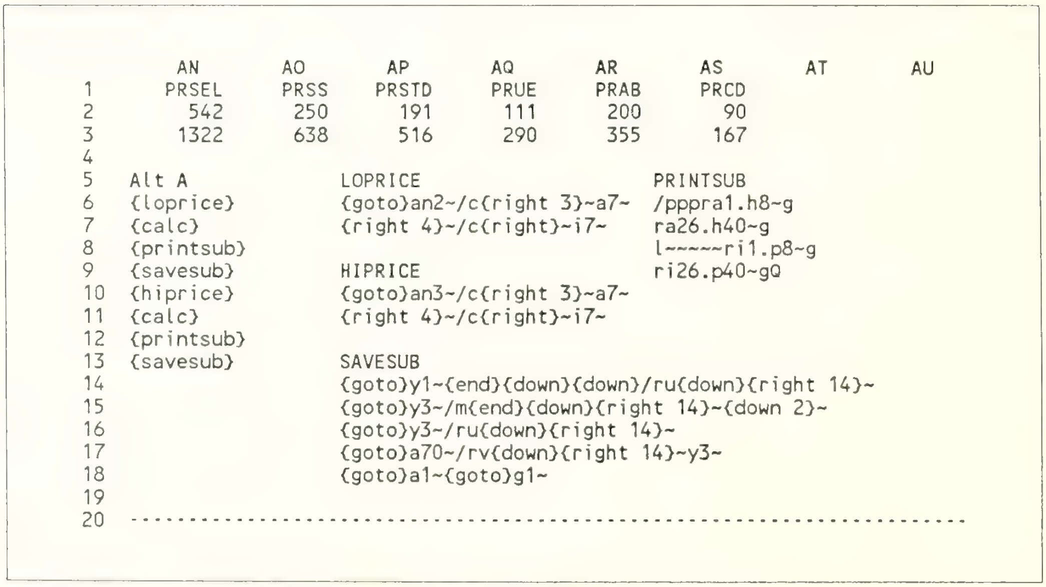
[2] Personal communication from Robert O. Curtis, mensurationist,
USDA Forest Service, Forestry Sciences Laboratory,
3625 93rd Ave. SW, Olympia, WA 98502.

6. Macro Feature in PRUNE-SIM

The problem in deciding the prices to use in the analysis is that the prices are needed now for a period 20 and more years from now. Future prices are not simply unknown; they are unknowable. We can look at price projections from various studies of supply and demand for timber and at historical trends, but since we cannot know what future prices will be we suggest looking at the financial return from pruning for a range of future prices. The prices used by PRUNE-SIM are the prices for lumber and veneer by product grade. The financial return from pruning depends on the difference in price between clear grades and lower grades of products. In addition to the price difference between AB and CD veneer, there is a cost saving for AB veneer produced from pruned logs. The average number of patches per sheet of AB veneer from pruned logs will be substantially less than the average number of patches per sheet of AB veneer from unpruned logs. The cost saving is added to the price in PRUNE-SIM to determine the increased return with pruning. The prices and costs used in the examples should be regarded as sample data sets and used only to verify program operation.

Many people will find this users guide more useful than any specific analysis we might publish because the number of regimes for which we can provide analyses is limited. The program allows users to do sensitivity analysis for the regimes that are most relevant to their situation; the combinations of prices, regimes, and other assumptions that may be desired in a sensitivity analysis will vary.



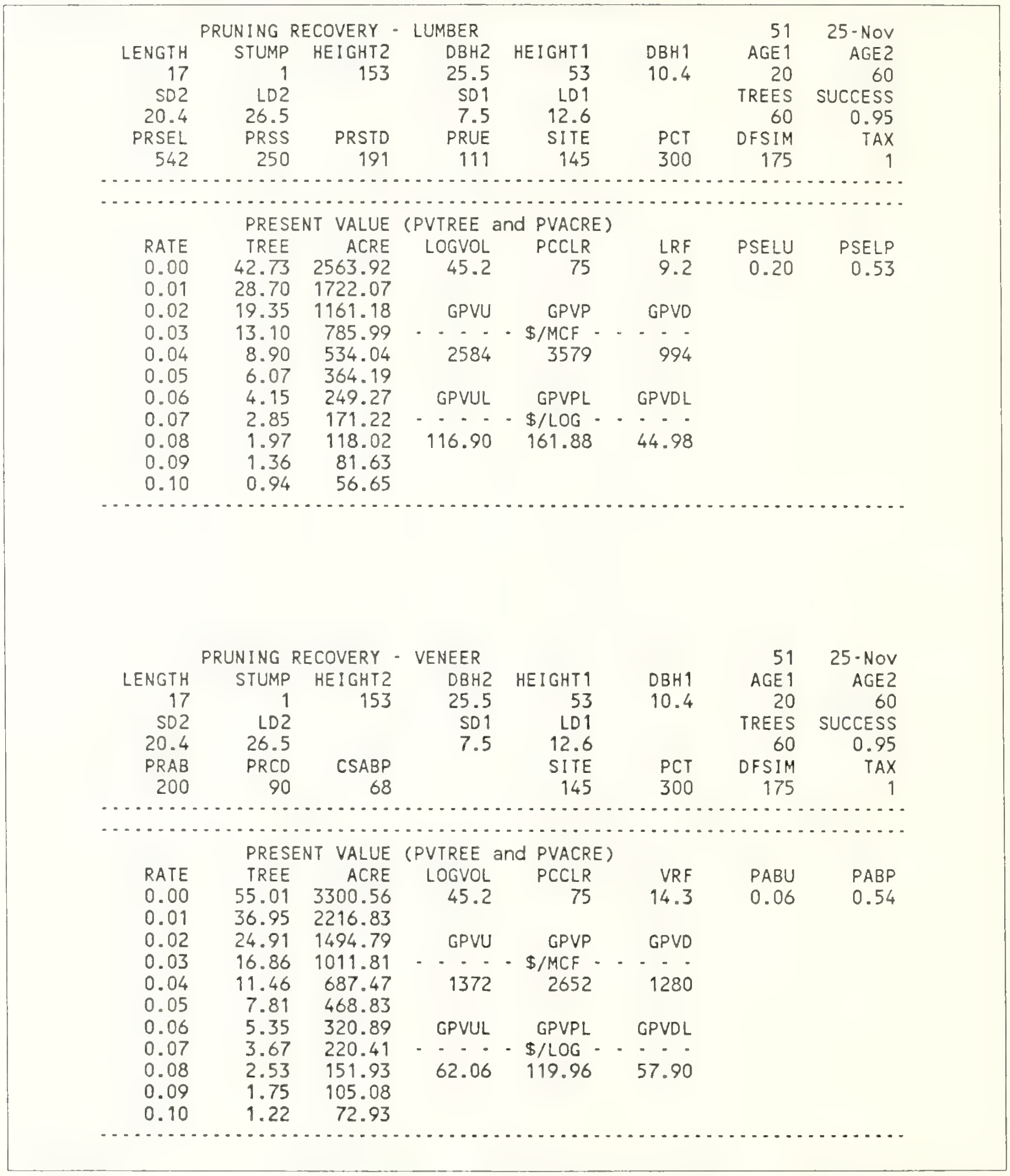
```
        AN        AO        AP        AQ        AR        AS        AT        AU
1      PRSEL     PRSS      PRSTD     PRUE      PRAB      PRCD
2        542      250        191      111       200        90
3       1322      638        516      290       355       167
4
5    Alt A              LOPRICE                         PRINTSUB
6    {loprice}          {goto}an2~/c{right 3}~a7~       /pppra1.h8~g
7    {calc}             {right 4}~/c{right}~i7~         ra26.h40~g
8    {printsub}                                         l~~~~~ri1.p8~g
9    {savesub}          HIPRICE                         ri26.p40~gQ
10   {hiprice}          {goto}an3~/c{right 3}~a7~
11   {calc}             {right 4}~/c{right}~i7~
12   {printsub}
13   {savesub}          SAVESUB
14                      {goto}y1~{end}{down}{down}/ru{down}{right 14}~
15                      {goto}y3~/m{end}{down}{right 14}~{down 2}~
16                      {goto}y3~/ru{down}{right 14}~
17                      {goto}a70~/rv{down}{right 14}~y3~
18                      {goto}a1~{goto}g1~
19
20   ------------------------------------------------------------------------
```

Figure 8—Portion of the spreadsheet containing the macro commands allowing sensitivity analysis for different product price assumptions. Letters and numbers refer to columns and rows in the spreadsheet.

One area in which sensitivity analysis may be desired is price premiums for clear grades of wood products. In determining priorities for pruning, the user may wish to do sensitivity analysis on age at time of pruning, age at time of harvest, and site index. A comparison of the return from pruning fertilized stands with pruning unfertilized stands would also be useful. There are some areas where sensitivity analysis can be done only by changing the equations in the spreadsheet model. These areas include the recovery equations (currently based on one recovery study) and tree profile equations (currently based on an unpublished equation).

For ease in doing sensitivity analyses, the spreadsheet contains a macro that calculates and prints results similar to figure 3 for both lumber and veneer for two sets of specified prices. Figure 8 shows the macro and the location for the two sets of prices. Once the desired sets of prices (arbitrarily referred to as "loprice" and "hiprice") are entered into locations AN2...AS3, the macro is invoked by holding down the "Alt" key and pressing "a." Figure 9 shows what is printed when this macro is invoked; in addition to these results, an abbreviated version of the results is moved to location Y3...AM6 (fig. 10). Whatever is currently at that location is moved down to make room for the new results. This provides a way to conveniently summarize and store the results from a series of analyses. These results can be graphed to facilitate comparisons of alternative regimes or assumptions. Figure 10 shows this output with the results from the sample run shown in figure 9. Column heading abbreviations and the location in the spreadsheet from which these numbers are taken are as follows:

ID = run identifier number entered at G1;
SITE = site index entered at E7;
A1 = age at time of pruning entered at G3;
PCT = number of trees after precommercial thinning entered at F7;
A2 = age at time of harvest entered at H3;
TRE = number of trees pruned entered at G5;
SUCC = proportion of pruned trees surviving to the final harvest entered at H5;
PRICE = the sum of the prices for each lumber or veneer grade (this variable is used to help identify runs without increasing the size of this array beyond one screen width);
TAX = 1 minus the applicable tax rate entered at H7;
PVT4 = present value per tree at a 4-percent interest rate reported at B33 for lumber and J33 for veneer;
PVA4 = present value per acre at a 4-percent interest rate reported at C33 for lumber and K33 for veneer;
PVT6 = present value per tree at a 6-percent interest rate reported at B35 for lumber and J35 for veneer;
PVA6 = present value per acre at a 6-percent interest rate reported at C35 for lumber and K35 for veneer;
PVT8 = present value per tree at an 8-percent interest rate reported at B37 for lumber and J37 for veneer;
PVA8 = present value per acre at an 8-percent interest rate reported at C37 for lumber and K37 for veneer.



```
            PRUNING RECOVERY - LUMBER                                  51    25-Nov
   LENGTH     STUMP   HEIGHT2      DBH2   HEIGHT1       DBH1        AGE1      AGE2
       17         1       153      25.5        53       10.4          20        60
      SD2       LD2                 SD1       LD1                  TREES   SUCCESS
     20.4      26.5                 7.5      12.6                     60      0.95
    PRSEL      PRSS     PRSTD      PRUE      SITE        PCT       DFSIM       TAX
      542       250       191       111       145        300         175         1
-------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------
                PRESENT VALUE (PVTREE and PVACRE)
     RATE      TREE      ACRE    LOGVOL     PCCLR        LRF       PSELU     PSELP
     0.00     42.73   2563.92      45.2        75        9.2        0.20      0.53
     0.01     28.70   1722.07
     0.02     19.35   1161.18      GPVU      GPVP       GPVD
     0.03     13.10    785.99  - - - - - $/MCF - - - - -
     0.04      8.90    534.04      2584      3579        994
     0.05      6.07    364.19
     0.06      4.15    249.27     GPVUL     GPVPL      GPVDL
     0.07      2.85    171.22  - - - - - $/LOG - - - - -
     0.08      1.97    118.02    116.90    161.88      44.98
     0.09      1.36     81.63
     0.10      0.94     56.65
-------------------------------------------------------------------------------------



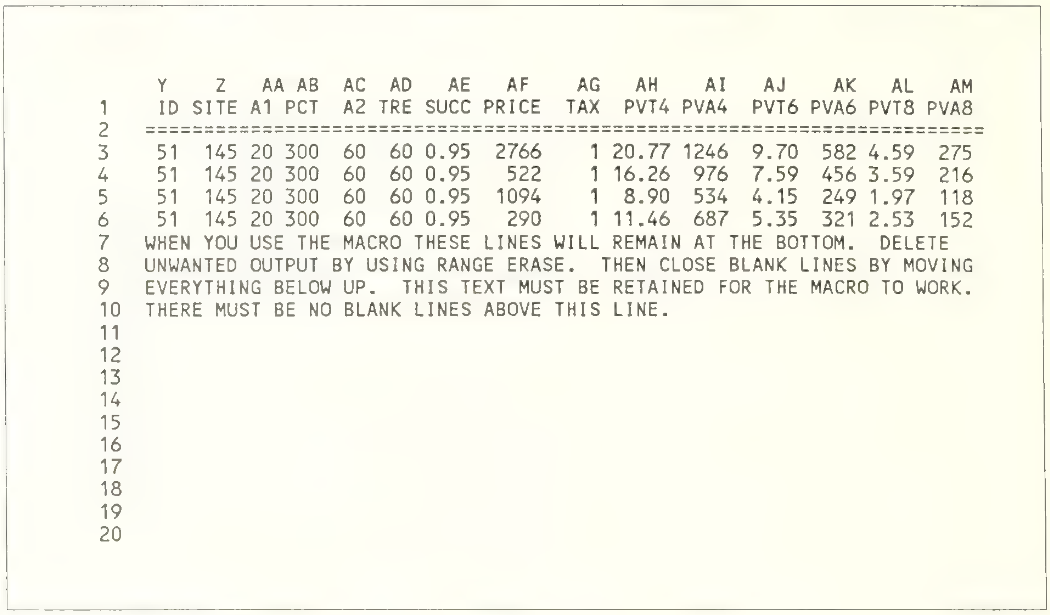

            PRUNING RECOVERY - VENEER                                  51    25-Nov
   LENGTH     STUMP   HEIGHT2      DBH2   HEIGHT1       DBH1        AGE1      AGE2
       17         1       153      25.5        53       10.4          20        60
      SD2       LD2                 SD1       LD1                  TREES   SUCCESS
     20.4      26.5                 7.5      12.6                     60      0.95
     PRAB      PRCD     CSABP                SITE        PCT       DFSIM       TAX
      200        90        68                 145        300         175         1
-------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------
                PRESENT VALUE (PVTREE and PVACRE)
     RATE      TREE      ACRE    LOGVOL     PCCLR        VRF        PABU      PABP
     0.00     55.01   3300.56      45.2        75       14.3        0.06      0.54
     0.01     36.95   2216.83
     0.02     24.91   1494.79      GPVU      GPVP       GPVD
     0.03     16.86   1011.81  - - - - - $/MCF - - - - -
     0.04     11.46    687.47      1372      2652       1280
     0.05      7.81    468.83
     0.06      5.35    320.89     GPVUL     GPVPL      GPVDL
     0.07      3.67    220.41  - - - - - $/LOG - - - - -
     0.08      2.53    151.93     62.06    119.96      57.90
     0.09      1.75    105.08
     0.10      1.22     72.93
-------------------------------------------------------------------------------------
```

Figure 9—An example of the results printed when the macro is executed.

```
            PRUNING RECOVERY - LUMBER                              51   25-Nov
   LENGTH      STUMP  HEIGHT2      DBH2   HEIGHT1      DBH1      AGE1     AGE2
       17          1      153      25.5        53      10.4        20       60
      SD2        LD2                SD1       LD1               TREES  SUCCESS
     20.4       26.5                7.5      12.6                  60     0.95
    PRSEL       PRSS    PRSTD      PRUE      SITE       PCT     DFSIM      TAX
     1322        638      516       290       145       300       175        1
------------------------------------------------------------------------------
------------------------------------------------------------------------------
                PRESENT VALUE (PVTREE and PVACRE)
     RATE       TREE     ACRE    LOGVOL     PCCLR       LRF     PSELU    PSELP
     0.00      99.73  5984.08      45.2        75       9.2      0.20     0.53
     0.01      66.99  4019.22
     0.02      45.17  2710.13      GPVU      GPVP      GPVD
     0.03      30.57  1834.46   - - - - - $/MCF - - - - -
     0.04      20.77  1246.42      6555      8876      2321
     0.05      14.17   850.01
     0.06       9.70   581.78     GPVUL     GPVPL     GPVDL
     0.07       6.66   399.62   - - - - - $/LOG - - - - -
     0.08       4.59   275.45    296.51    401.49    104.98
     0.09       3.18   190.52
     0.10       2.20   132.22
------------------------------------------------------------------------------
```

```
            PRUNING RECOVERY - VENEER                              51   25-Nov
   LENGTH      STUMP  HEIGHT2      DBH2   HEIGHT1      DBH1      AGE1     AGE2
       17          1      153      25.5        53      10.4        20       60
      SD2        LD2                SD1       LD1               TREES  SUCCESS
     20.4       26.5                7.5      12.6                  60     0.95
     PRAB       PRCD    CSABP                SITE       PCT     DFSIM      TAX
      355        167       68                 145       300       175        1
------------------------------------------------------------------------------
------------------------------------------------------------------------------
                PRESENT VALUE (PVTREE and PVACRE)
     RATE       TREE     ACRE    LOGVOL     PCCLR       VRF      PABU     PABP
     0.00      78.09  4685.28      45.2        75      14.3      0.06     0.54
     0.01      52.45  3146.88
     0.02      35.37  2121.92      GPVU      GPVP      GPVD
     0.03      23.94  1436.31   - - - - - $/MCF - - - - -
     0.04      16.26   975.89      2533      4350      1817
     0.05      11.09   665.52
     0.06       7.59   455.51     GPVUL     GPVPL     GPVDL
     0.07       5.21   312.88   - - - - - $/LOG - - - - -
     0.08       3.59   215.67    114.57    196.77     82.20
     0.09       2.49   149.17
     0.10       1.73   103.52
------------------------------------------------------------------------------
```

Figure 9—(continued)



```
      Y    Z   AA AB   AC  AD   AE    AF     AG   AH    AI    AJ    AK   AL   AM
1     ID SITE A1 PCT   A2 TRE SUCC PRICE   TAX  PVT4 PVA4  PVT6 PVA6 PVT8 PVA8
2    ======================================================================
3     51  145 20 300   60  60 0.95  2766     1 20.77 1246  9.70  582 4.59  275
4     51  145 20 300   60  60 0.95   522     1 16.26  976  7.59  456 3.59  216
5     51  145 20 300   60  60 0.95  1094     1  8.90  534  4.15  249 1.97  118
6     51  145 20 300   60  60 0.95   290     1 11.46  687  5.35  321 2.53  152
7    WHEN YOU USE THE MACRO THESE LINES WILL REMAIN AT THE BOTTOM.  DELETE
8    UNWANTED OUTPUT BY USING RANGE ERASE.  THEN CLOSE BLANK LINES BY MOVING
9    EVERYTHING BELOW UP.  THIS TEXT MUST BE RETAINED FOR THE MACRO TO WORK.
10   THERE MUST BE NO BLANK LINES ABOVE THIS LINE.
11
12
13
14
15
16
17
18
19
20
```

Figure 10—An example of the summary results stored in the spreadsheet when the macro is executed. Letters and numbers refer to columns and rows in the spreadsheet.

Summary

This spreadsheet template provides a means for simulating the difference between the financial returns of pruned and unpruned stands. It is accessible and easy to use for anyone who has access to a personal computer and LOTUS 1-2-3 software. This program should be widely applicable to coast Douglas-fir. There are at least two sources of conservative bias in the results that this model produces. One is that the unpruned recovery is based on stands that were grown with relatively close spacing. Unpruned trees from stands that are grown at wider spacing will likely have lower grade recovery than predicted by the model, making the increase in value after pruning larger. Another source of conservative bias is that the lumber recovery for pruned logs is based on processing that was more production oriented than grade oriented. A mill that is oriented to sawing for grade would likely get higher grade recovery from pruned logs than predicted by the model. On the other hand, the user must exercise caution in making price assumptions. Clear wood products from pruned young-growth logs have a different appearance than clear wood products from old growth. There is likely to be market resistance to clear wood products from pruned young growth. The extent of this resistance cannot be measured. Historical experience indicates, however, that as any high quality resource gets scarcer and more expensive, people become more creative in using substitutes. Clear wood products from pruned young growth should be a close substitute for clear wood products from old growth for many uses; as old growth clear wood becomes more expensive, the market resistance to young growth clear wood is likely to diminish. A final note of caution. The predicted recovery for pruned logs that fall outside the range of diameters at time of pruning and time of harvest should be regarded as suspect. Results using any such extrapolations should be scrutinized carefully.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.305 meter
1 cubic foot = 0.028 cubic meter
1 acre = 0.4047 hectare

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GPO 592-066/80043

Fight, Roger D.; Cahill, James M.; Snellgrove, Thomas A.; Fahey, Thomas D. 1987. PRUNE-SIM users guide. Gen. Tech. Rep. PNW-GTR-209. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

PRUNE-SIM is a spreadsheet template (program) that allows users to simulate a financial analysis of pruning coast Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*). The program estimates the increase in product value resulting from pruning the butt 17-foot log. Product recovery information is based on actual mill experience with pruned and unpruned logs for both sawn and peeled products. Users must supply tree descriptions from sources of growth and yield information and product prices. The program calculates the difference in value for trees and stands with and without pruning. The present value of this difference represents the maximum amount that could be spent on pruning without reducing the rate of return on the investment below the specified rate. The LOTUS 1-2-3 spreadsheet program was used to develop PRUNE-SIM. The user needs a basic knowledge of spreadsheets to use this program.

Keywords: Simulation, pruning, Douglas-fir (coast), forest product value, product recovery.

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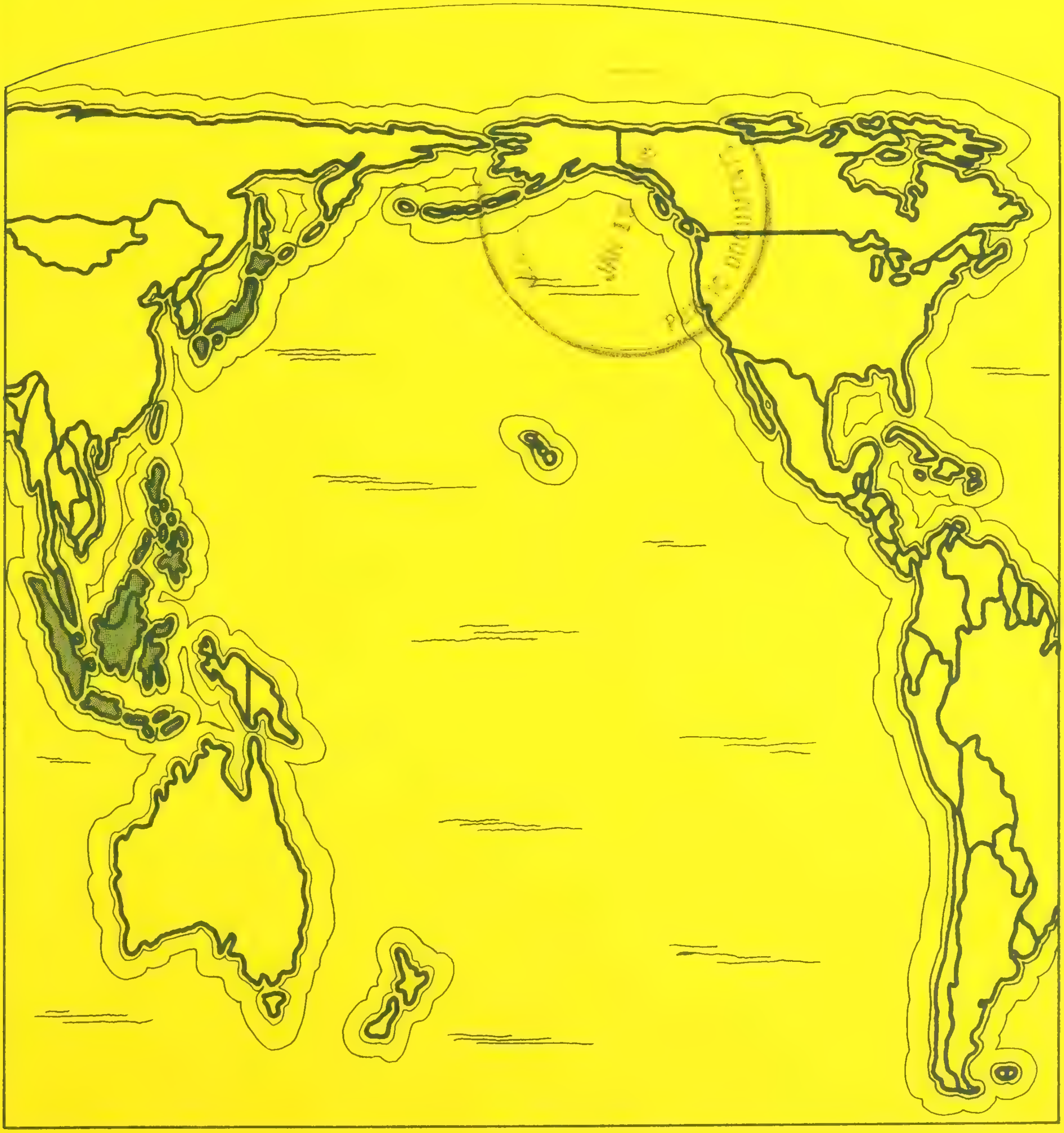
Report
PNW-GTR-210

Modeling Japan–South Seas Trade in Forest Products

Jeffrey R. Vincent



Author

JEFFREY R. VINCENT was a volunteer, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, in the summer of 1985, when this research was carried out. His present address is: Department of Forestry, Michigan State University, East Lansing, Michigan 48824-1222.

Abstract

Vincent, Jeffrey R. 1987. Modeling Japan-South Seas trade in forest products. Gen. Tech. Rep. PNW-GTR-210. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 1987. 28 p.

The international trade of forest products has generated increasing research interest, yet experience with modeling such trade is limited. Primary issues include the effects of trade barriers and exchange rates on trade patterns and national welfare. This paper attempts to add to experience by modeling hardwood log, lumber, and plywood trade in a region that has been mostly overlooked: East Asia, specifically Japan and the South Seas nations (Indonesia, Malaysia, and the Philippines). Japan-South Seas trade is important because of its significance in global forest-products trade and because of the large changes in trade barriers and exchange rates since 1970. In this paper, I describe the development of an economic model, JIMP, for investigating trade issues in the region. The model uses reactive programming to solve for a spatial equilibrium. Preliminary results suggest that: (1) restrictions on log exports will benefit South Seas nations only if the nations act together, and (2) relatively small fluctuations in exchange rates influence trade patterns as much as do large changes in tariffs.

Keywords: Trade modeling, Japan, South Seas nations, hardwood products, trade barriers, exchange rates, spatial equilibrium, reactive programming.

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Introduction

Awareness of the importance of understanding international markets for forest products is growing among forest economists both in the United States and abroad. Attention to issues such as the impacts of exchange rates and tariffs on trade patterns and the well-being of nations is increasing. The most common method for studying such issues is to build and simulate a computer-based model of the international economy. Modeling is attractive because it provides a structured, quantitative approach. Notable research efforts include the Global Trade Model developed at the International Institute for Applied Systems Analysis (IIASA) (Dykstra and Kallio 1984), Adams's (1985) African-European trade model, and the World Assessment Market Model being developed by the USDA Forest Service (Brooks, in press). Despite these efforts, however, knowledge of how to model international trade flows remains rudimentary.

Worldwide, solid-wood products (saw logs, veneer logs, sawnwood, and panel products) traded in 1983 had a total value of more than $20 billion. Hardwood products made up $8.6 billion, or 43 percent, of the total. Trade in hardwood products is concentrated in eastern Asia. In 1983, Japan—the world's second largest importer of forest products, after the United States—imported hardwood logs worth $1.6 billion, more than half the value of hardwood logs traded worldwide. During the past three decades, most of Japan's imports of hardwood logs, hardwood sawnwood, and hardwood plywood have come from the South Seas region: Indonesia, Malaysia, the Philippines, and several other island nations. This region is by far the world's most important exporter of hardwood products, especially hardwood logs. Japan-South Seas trade is subject to various tariff and nontariff barriers; Japan has sought to exclude the import of processed products, and the South Seas nations have sought to restrict log exports.

Japan is an increasingly important market for U.S. and Canadian forest products. In 1983, Japan was the largest importer of softwood logs and softwood sawnwood produced in Canada and the United States. Products from the South Seas nations compete in the Japanese market with products from North America, and there is evidence that direct competition will increase. Japan recently eased restrictions on domestic use of softwood plywood, and, because of log-export restrictions by South Seas nations, it has experimented with western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) as a substitute for South Seas logs in the manufacture of plywood (Schreuder and Vlosky 1985).

This paper reports a study of the effects of log-export embargoes, tariffs, and exchange rates on trade between Japan and the South Seas nations. The study required the development of an economic model of the production, consumption, and trade of forest products in Japan, Indonesia, Malaysia, and the Philippines. Other nations in the South Seas region, such as Papua-New Guinea and the Solomon Islands, were not included in the model because they were much less important exporters during the period studied. The model is named "JIMP," an acronym based on the first letter of the name of each nation included in it. The products studied are hardwood logs, sawnwood, and plywood.

In this paper, I review historic features of the trade and discuss previous efforts to model it; I then describe how the model was assembled and how it is solved. Next I discuss the results of simulation exercises designed to throw light on major policy questions. Finally, I summarize the findings and point out ways in which the model could be improved. Results reported in this paper are preliminary. Nevertheless, they do indicate that a supply-demand analysis of forest-products markets in Japan and the South Seas nations is feasible and is useful for understanding the factors that influence trade flows in the region.

Trade Patterns and Price Trends: 1970-83

Log imports have constituted more than half of total log and hardwood log consumption in Japan. Both consumption and imports of hardwood logs have declined, however, registering sharp dips during the recessions that followed the oil shocks in 1973-74 and 1978-79 (fig. 1). Figure 1 also shows that imports from the South Seas nations have constituted nearly all of Japan's imports of hardwood logs. Plywood has been the most important (60-80 percent by volume) end use for Japan's imports of logs from the South Seas.

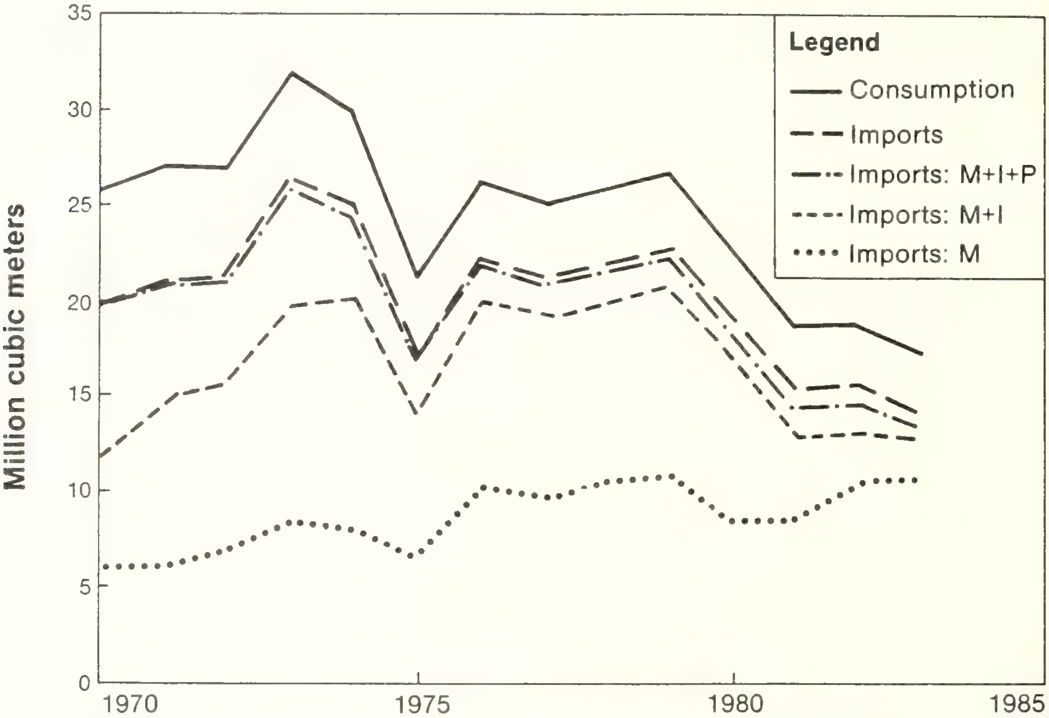

Figure 1—Hardwood-log consumption in Japan, 1970-83. M is Malaysia, I is Indonesia, P is Philippines.

Three points should be noted about the South Seas nations as log exporters. First, production of logs has increased in Indonesia and Malaysia but decreased in the Philippines (fig. 2), where harvesting began earlier. Second, exports to Japan have comprised more than half of total exports for each nation. Finally, figure 1 shows that exports to Japan by Indonesia and the Philippines have declined because of more stringent export restrictions. Data on export restrictions are summarized in table 1, which shows that South Seas nations have used both taxes and quotas to reduce log exports. Sabah and Sarawak are the two major log-exporting regions of Malaysia; for this reason, the restrictions imposed by Peninsular Malaysia have had little impact on Malaysia's log exports.

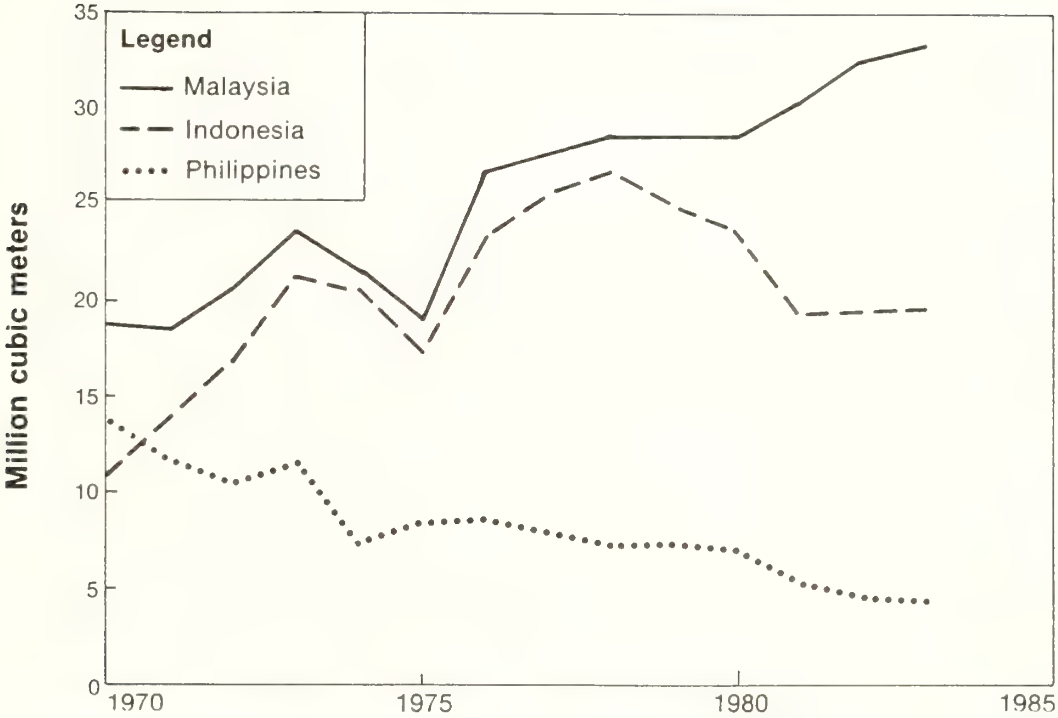

Figure 2—Hardwood-log production in South Seas nations, 1970-83.

Imports of solid-wood forest products by the South Seas nations have been virtually nil. The explanation is twofold: in the past, forest resources were abundant; and since the mid-1970's, log-export restrictions have helped maintain supplies for domestic processors, and import barriers against processed products have kept out competing products.

The story for Japanese sawnwood and plywood imports has been different from that for logs: Figures 3 and 4 show that imports have constituted a small portion of hardwood sawnwood and total plywood consumption in Japan. Although all three South Seas nations have increased production and exports of sawnwood and plywood (since the mid-1970's, Indonesia has constructed more than 100 plywood mills), they have exported little to Japan. Import barriers help explain this situation: Japan has a 10-percent tariff on South Seas sawnwood and a 17-percent (19.3-percent before 1985) tariff on South Seas plywood. These nominal rates translate into effective rates of protection that are several times higher because Japan has no import tariff on logs and because log price is a significant portion of production costs.[1]

---

[1] An excellent exposition of the notion of effective rate of protection is given in Corden (1966). Essentially, the effective rate of protection is the ratio of value-added for a domestic industry to value-added for the same industry in the rest of the world. The rate increases as protection of final products increases, as protection of intermediate inputs decreases, and as the intermediate input comprises a larger portion of production costs.

Table 1—Trade barriers on products from the South Seas[1]

Item	Logs	Sawnwood	Plywood
		Percent	
Export taxes: 2/			
Indonesia	10 (1971) 20 (1978)	5 (1979)	0
Malaysia--			
Peninsular	10 (1970) 15 (1972) 20 (1980)	5 (1970) 3/	5 (1970) 3/
Sabah	3 (1978)	0	0
Sarawak	5 (1974) 10 (1980)	0	0
Philippines	25 (1977)	0	0
Import tariffs:			
Japan	0 (1970)	10 (1972) 8 (1985)	20 (1972) 17 (1985)
Indonesia	15	15	30
Malaysia	15 (1957) 20 (1978)	15 (1957) 20 (1978)	20 (1957) 25 (1978) 45 (1984)
Philippines	10 (1983)	20 (1983)	39 (1983)
Log export quotas:			
Indonesia	(4/) (1978) (5/) (1980) (6/) (1985)		
Malaysia--			
Peninsular	(4/) (1972) (5/) (1976) (6/) (1985)		
Sabah	(5/) (1975)		
Sarawak	(4/) (1979)		
Philippines	(5/) (1976)		

1/ All values are current unless otherwise indicated. Approximate dates when trade barriers were imposed are given in parentheses.
2/ Does not include royalties.
3/ Repealed 1974.
4/ Embargo on selected species.
5/ Quota.
6/ Total embargo.
Sources: Various. Major sources include country tariff schedules, Foreign Agricultural Service Attache Reports, Japan Lumber Journal (December 31, 1984), and Gillis (1980).

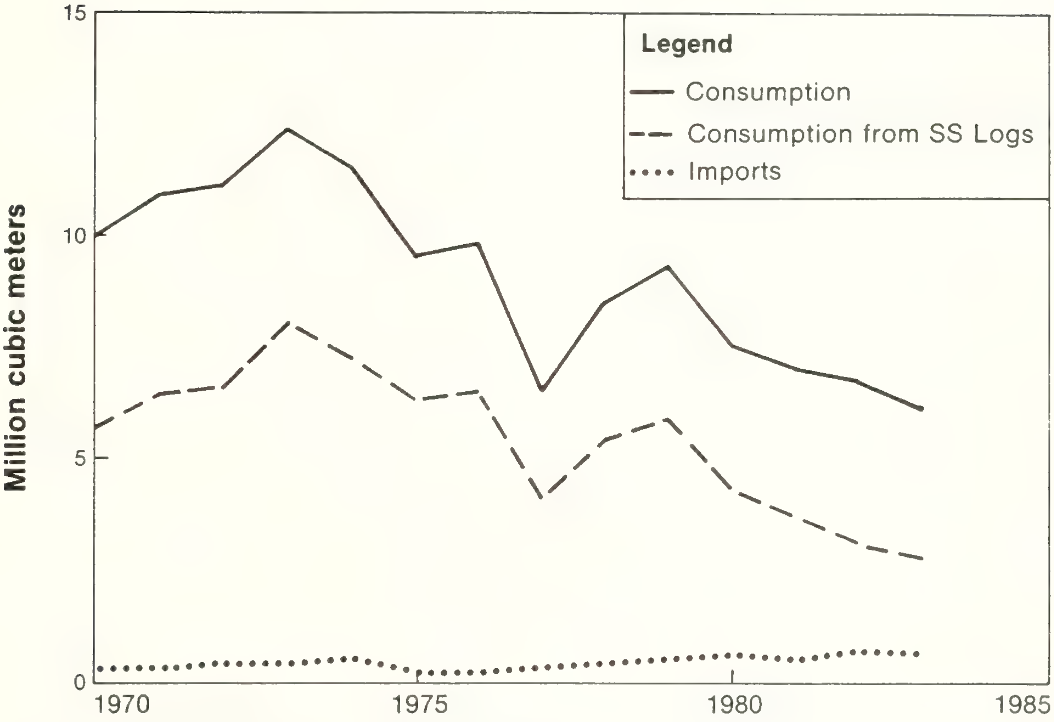

Figure 3—Hardwood-sawnwood consumption in Japan, 1970-83. SS = South Seas.

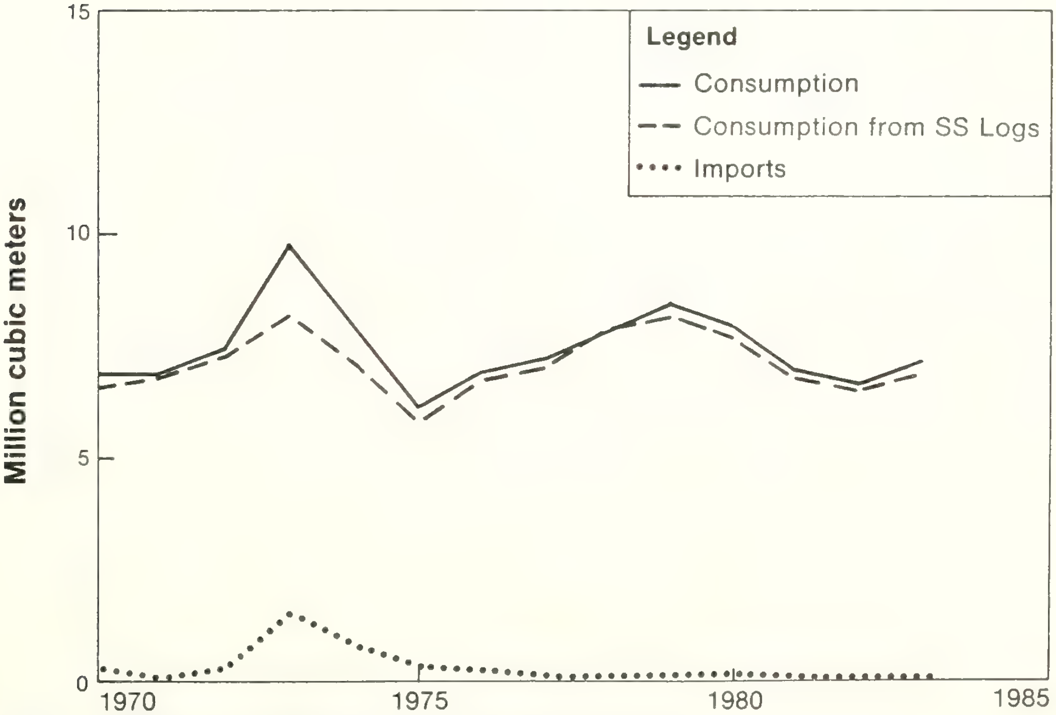

Figure 4—Plywood consumption in Japan, 1970-83. SS = South Seas.

Figures 3 and 4 show that Japanese consumption of plywood and especially sawnwood has declined from the 1973 peaks. These declines explain, by way of derived demand, the reduced log consumption noted above. The figures show that the major portions of plywood (>95 percent) and hardwood sawnwood (50-60 percent) consumed in Japan have been manufactured in Japan from logs from the South Seas.

Figure 5 shows that real prices of South Seas logs in Japan have been relatively constant and that real prices of plywood made from South Seas logs have declined markedly. Real prices of South Seas sawnwood, however, have increased steadily. This difference in relative price movements may explain why Japanese consumption of sawnwood has declined more rapidly than consumption of plywood: There has been less incentive to find substitutes for plywood than for sawnwood. Note that all three prices increased faster than the general price level during the 1973-74 and 1978-79 oil shocks.

Previous Modeling Efforts

Extant models of forest-products trade are too highly aggregated in terms of either products or regions for studying the factors that might influence trade between Japan and the South Seas nations. The Global Trade Model of IIASA has disaggregated forest products, but it treats the South Seas nations as a single region. Nomura and Yukutake (1982) presented a comprehensive model of the forest-products industry of Japan that included submodels of foreign supply, but they also treated the South Seas nations as one region.

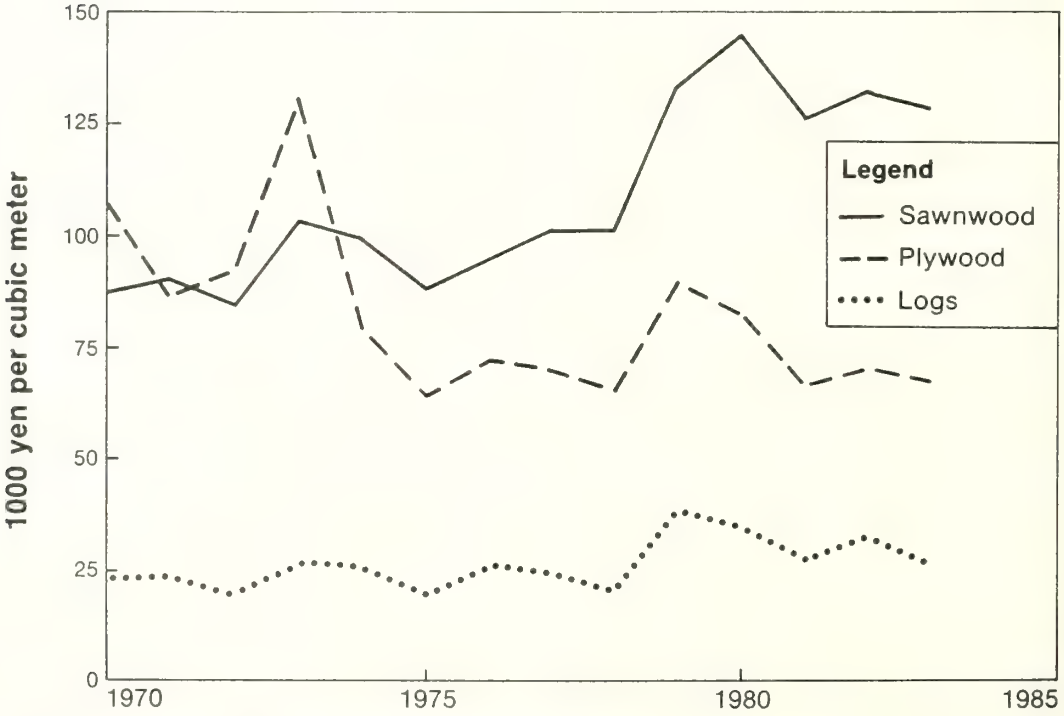

Figure 5—Real prices of South Seas products in Japan, 1970-83.

Treating the South Seas nations as individual regions is desirable for three reasons: Their forest resources and industries differ in important ways, they are not following identical trade policies, and their currencies have not been equally stable. The first two points were discussed above. Regarding the third reason, from 1970 to 1984 the strengths of the rupiah (Indonesia), ringgit (Malaysia), and peso (Philippines) all weakened compared with the yen. The exchange rates per yen increased about 325 percent, 10 percent, and 325 percent, respectively, and each currency had a change in annual value of as much as 25 percent at least once. We will see that simulation results support the hypothesis that these fluctuations in currencies have significantly influenced trade patterns.

The Model

Major Features of JIMP

Adams's (1985) model of trade between Africa and Europe was used as a guide for constructing JIMP. The two models share two major characteristics. First, both are spatial-equilibrium models, which means that: (1) They include more than one supply region and more than one demand region; (2) the supply regions and the demand regions correspond to real-world regions separated by geographic distances; (3) in equilibrium, prices for a given commodity are equal in all regions after adjustments are made for transportation costs, tariffs, and exchange rates; and (4) in equilibrium, the sum of quantities supplied by all regions equals the sum of quantities demanded. This type of model is useful for modeling trade because it allows study of how both domestic and export markets are affected by trade. Spatial equilibrium models are discussed in more detail by Adams and Haynes (1987).

Second, both models share the same method of solution—reactive programming. This algorithm is well suited for solving spatial equilibrium models, and it determines the bilateral trade flows that occur in equilibrium. That is, a reactive-programming solution tells us not only how much a particular region exports but also how much it exports to each of the other regions. Information on bilateral flows is useful for validating a model and is often of interest to model users. The reactive-programming algorithm was first described by Tramel and Seale (1959). The actual algorithm used in solving both models was the one developed by King and Ho (1972), which was modified by Adams (1985) to solve for an equilibrium when there are two market levels, logs and sawnwood.

The JIMP model includes four primary supply and demand regions—Japan and the three South Seas nations. It includes three products—tropical hardwood logs, and sawnwood and plywood made from tropical logs. To simplify modeling, I assumed that all logs are consumed in the manufacture of either sawnwood or plywood. This is not strictly true because some logs are consumed in the manufacture of other wood-based panel products, such as veneer. Products made from other hardwoods or softwoods are not included in the model. Such products are uncommon in the South Seas nations, and tropical hardwood products are more important than other hardwood products in Japan. A consequence of this product definition is that the model contains no log supply equation for Japan.

The model proper consists of a set of supply and demand equations for each product in each region. These are domestic supply and domestic demand equations, not export supply and import demand equations. Given exogenous values for transportation costs, exchange rates, and tariffs in a given year, the reactive-programming algorithm solves this set of simultaneous equations for spatial equilibrium. The price relation that must hold in equilibrium, described above, can be expressed by:

$$P(j) = [P(i) \times (1 + t(i)) + T(ij)] \times e(ij) \times (1 + t(j)); \qquad (1)$$

where:

$P(j)$ = demand region price;

$P(i)$ = supply region price;

$t(i)$ = ad valorem export tariff;

$T(ij)$ = transfer cost from supply to demand region;

$e(ij)$ = exchange rate;

$t(j)$ = ad valorem import tariff.

If $i=j$, then "trade" is actually the portion of domestic production that is consumed domestically, and $t(i)=t(j)=T(ij)=0$ and $e(ij)=1$. The simple relation expressed by equation (1) is perhaps the most fundamental element of the computer code for the reactive-programming algorithm.

Trade flows to and from the rest of the world (ROW)—that is, imports from or exports to nations other than Japan and the three South Seas nations—must be taken into account too. These flows are modeled in two ways, depending on their size. Minor trade flows, such as imports by South Seas nations and exports by Japan, are fixed at historical levels by adjusting the intercepts of estimated supply and demand equations. This procedure assumes, of course, that equations are written with quantity as the dependent variable. Exports to the ROW by South Seas nations were frequently quite large, and these more significant flows were modeled by estimating individual ROW import-demand equations for each product of a given nation.

Data

Eight annual data series were needed for each product and region: domestic production, exports by destination, imports by source, domestic consumption, domestic producer prices, domestic consumer prices, f.o.b. (free on board) prices for exports, and c.i.f. (cost, insurance, and freight) prices for imports. Primary sources of data were the "Yearbook of Forest Products" ("Yearbook") published annually by the Food and Agricultural Organization of the United Nations, the "Japan Lumber Journal," and the "Monthly Report of Japan Timber Market." Not all data series were complete or available, especially for nations in the South Seas. I dealt with missing data by shortening estimation periods, by using other data series as proxies, or by constructing artificial data from other series. Additional details on data used in the model are given in appendix 1.

Transfer Costs—From equation (1), it is clear that the solution of a spatial-equilibrium model requires data on transfer costs, which are the sum of transportation and handling costs. The "Japan Lumber Journal" contains data on transportation costs for shipments of logs to Japan, but these data do not include handling charges. Instead of using these data directly and to estimate transfer costs for sawnwood and plywood, I calculated all transfer costs by inserting price, tariff, and exchange rate data into equation (1) and solving for the residual, T(ij).

Residual transfer costs were calculated only for trade flows from the South Seas nations to Japan. For flows from Japan to the South Seas and for flows between individual nations in the South Seas, transfer costs were set equal to an arbitrarily large number. This procedure prevented these flows from entering the model solution, reflecting the empirical fact that high actual transport costs and steep import barriers have forced trade flows in these directions to be essentially zero. This procedure is more acceptable for historical analysis than for forecasting because trade between South Seas nations appears to be increasing.

Trade Barriers—Available data on tariffs and quotas are summarized in table 1. Ad valorem tariff rates are incorporated directly into the model through equation (1). Per-unit (specific) tariffs are taken into account insofar as they are a component of the residually calculated transfer costs.

Quotas on log exports have become especially significant since 1980, the most extreme example being the embargo imposed by Indonesia on January 1, 1985. Quotas can be included in spatial-equilibrium models as upper bounds on trade flows. Although they should be included if model solutions are to reproduce real-world behavior, they are not included in JIMP. The absence of upper bounds did not affect the simulation results reported in "Simulations," however, because JIMP has been solved only for 1980 values of exogenous variables and because the quotas that existed in 1980 were not binding for historical or simulated flows.

Estimation

Supply and demand equations were estimated in linear form for 1970-83. This period was chosen because F-tests indicated that the coefficients of supply and demand equations were significantly different for 1961-69 and 1970-83. Such structural change is to be expected in developing countries with large changes in processing capacity during the estimation period. Malaysian sawnwood supply and demand equations were estimated for 1965-78 because data were not available for the years after 1978.

Because the number of observations was small (14), the estimation technique used was ordinary least squares, not two-stage least squares. Quantity was regressed on price and other explanatory variables that economic theory predicts should shift supply and demand equations. Prices were in the domestic currency of each nation, not in a common currency such as the U.S. dollar. Consumers and producers were assumed to make decisions based on prices in their own currency. All equations were estimated in two forms, one with nominal prices and one with real prices. The decision between the two forms was based on goodness of fit (measured by R-squared), significance of coefficient estimates (measured by t statistics), and correctness of signs. Heaviest weight was given to coefficient significance and sign correctness.

A complete list of the estimated equations is given in appendix 2. Because of the preliminary nature of this research, the final set of estimated equations includes several specifications for equations that describe the supply or demand of the same product. The standard demand shifter was assumed to be current gross domestic product (GDP), although in some cases lagged GDP, change in GDP, or housing starts yielded better fits. Supply shifters that were tried included log price (for sawnwood and plywood equations), wage rate (available only for Japan and the Philippines), producer price index (the GDP deflator for Malaysia), and various measures of energy cost (oil price index, percentage change in oil price index, dummy variables for years after the 1973-74 and 1978-79 oil shocks). Lagged quantity was used in some equations to capture slowly moving changes not picked up by other variables. No measures of capital services were used in supply equations; lack of data on this crucial variable is a chronic problem in forest-sector modeling.

The use of an oil-price variable is perhaps unusual. On the one hand, energy costs constitute only a small portion of wood-processing costs. Worse, oil prices are a macrovariable that might be collinear with demand shocks, and thus their inclusion in a supply equation might taint the equation with demand-side effects. On the other hand, energy costs, no matter how insignificant, are an element of wood-processing costs, and a supply equation would be misspecified if they were excluded. Moreover, oil price might be useful as a proxy for other costs, such as wage rates and costs of capital services, when data for such costs are missing. Indeed, wage rates were not available for Indonesia and Malaysia, and costs of capital services were not available for any of the nations. Finally, oil prices during the period studied were negatively correlated with GDP, and so their usefulness in explaining real and nominal price increases during the inflationary 1970's cannot be ascribed to their being a proxy for demand increases.

The estimated sawnwood supply equation for Japan lacks a log-price term because a satisfactory specification that included log price could not be found. Without a log-price term, the Japanese sawnwood supply equation is not sensitive to log-price changes, and this clearly biases simulation results. This equation is the one in the model that most needs modifying; one possible solution would be to restrict the log-price coefficient to be equal to some exogenously chosen value.

Single-period price elasticities for the equations are given in table 2.

Table 2—Own-price elasticities of estimated equations[1]

Equation	Japan	Indonesia	Malaysia	Philippines
Log supply	([2])	0.51	0.37	0.32
Sawnwood supply	0.38	.73	.73	1.97
Plywood supply	.42	.53	.57	1.60
Sawnwood demand	-.49	-.58	-.38	-.59
Plywood demand	-.18 [3]	-.22	-1.56	-1.44

[1] Own-price elasticity = percentage change in the quantity of a product produced or consumed divided by percentage change in the price of the product. Calculated from the mean (for the estimation period) values of the quantity and price variables and from the estimated coefficient on price.
[2] Not applicable.
[3] Exogenous estimate based on Wibe (1984).

Solution

The JIMP model has been solved for 1980 values of the exogenous variables, which include transfer costs, tariffs, exchange rates, and the shifters in supply and demand equations. Solving the model required rearranging each equation so that price was a function of quantity and exogenous shifters. Then, 1980 values for the shifters were inserted to produce reduced-form equations in which price was a function of only quantity and a constant term. I derived demand equations for logs by using processing-recovery rates to combine each region's sawnwood and plywood supply equations.

The final set of 27 equations—11 estimated supply equations, 12 estimated demand equations, and 4 derived demand equations for logs—was solved for prices, production and consumption quantities, and bilateral trade flows by use of reactive programming. Adams's (1985) interactive version of the reactive-programming algorithm was modified to include an additional product (plywood), to add export and import tariffs, and to add exchange rates.

Validation

Model validation relates to the behavior of the entire system of equations during solution. Since JIMP has been solved only for a single year, model validation is not yet extensive. As shown in table 3, however, baseline results were reasonably close to actual 1980 values. Only 5 of 35 prices or quantities deviated from historical values by more than 10 percent. Deviations were least for the log market, followed by sawnwood. The simulated Malaysian sawnwood price was too high by nearly 60 percent, and this was probably a consequence of lack of data after 1978 in estimating the Malaysian sawnwood supply and demand equations.

Table 3—Deviations of baseline simulation results from 1980 data

Product and region	Price	Production	Consumption
		Percent	
Logs:			
Japan	-1.2	(1/)	-0.8
Indonesia	-1.6	-3.7	-2.0
Malaysia	-2.1	+.5	-8.6
Philippines	-1.4	-7.9	-13.4
Sawnwood:			
Japan	-2.3	+2.5	-8.4
Indonesia	-8.1	-.4	+4.0
Malaysia	+59.0	(2/)	(2/)
Philippines	-5.2	-16.0	-6.6
Plywood:			
Japan	-1.5	-2.5	-2.4
Indonesia	+41.5	-8.3	+1.0
Malaysia	+6.5	-2.1	+.5
Philippines	-2.3	-6.4	-40.9

1/ Not applicable because Japan does not produce tropical hardwood logs.
2/ Data for 1980 not available.

A final check is the similarity of actual and simulated trade flows to Japan. Table 4 shows that simulated flows of logs were close to actual values. Simulated sawnwood and plywood flows resembled actual flows in magnitude; both were very small.

Table 4—Actual and simulated trade flows to Japan

Product and region 2/	Simulation 1/											
	A	B	1	2	3	4	5	6	7	8	9	10
						Thousand cubic meters						
Logs:												
I	8905	7593	8292	0	14319	8136	0	7994	7591	8626	6367	7504
M	8373	9425	7906	14668	0	9942	0	9366	9651	8443	11017	9345
P	1166	1281	1609	2623	2894	0	0	71	731	1053	949	1132
Sawnwood:												
I	126	0	377	862	0	0	2440	130	262	349	0	0
M	198	0	0	0	902	0	1859	0	0	0	0	0
P	192	0	87	0	0	184	0	72	251	0	26	325
Plywood:												
I	20	0	0	291	0	0	2411	17	0	0	0	0
M	12	0	74	0	299	0	1276	62	0	0	0	0
P	0	41	191	18	27	119	2141	302	113	31	29	142

1/ A = Actual data; B = baseline simulation; 1 = free trade (no tariffs); 2 = Indonesian log-export embargo; 3 = Malaysian log-export embargo; 4 = Philippine log-export embargo; 5 = South Seas log-export embargo; 6 = 100-percent log-export surcharge by South Seas nations; 7 = Japanese yen 10 percent stronger; 8 = Indonesian rupiah 10 percent weaker; 9 = Malaysian ringgit 10 percent weaker; 10 = Philippine peso 10 percent weaker.

2/ I = Indonesia; M = Malaysia; P = Philippines.

Simulations

General Remarks

Ten static simulations were run with JIMP. These simulations are counterfactual in the sense that they predict the situation in 1980 as it would have been if the historical situation had been modified as in the simulation. Results of these simulations are given in tables 4 and 5. Table 4 shows actual and simulated trade flows to Japan. Table 5 shows direction of welfare changes for each nation under each simulation, compared with the baseline case. Welfare measures are defined in "Results: Log-Export Embargoes."

Table 5—Direction of changes in welfare[1]

Welfare measure	Simulation 2/ 1	2	3	4	5	6	7	8	9	10
Consumer surplus:										
Sawnwood--										
Japan	+	+	+	+	-	+	+	+	+	+
Indonesia	+	+	-	-	-	+	-	-	+	+
Malaysia	+	-	+	-	+	+	-	+	-	+
Philippines	-	-	-	+	-	+	-	+	+	-
Plywood--										
Japan	+	-	-	+	-	-	+	+	+	+
Indonesia	-	+	-	-	-	+	-	-	+	+
Malaysia	-	-	+	-	-	-	-	+	-	+
Philippines	-	-	-	+	-	-	-	+	+	-
Producer surplus:										
Logs--										
Indonesia	+	-	+	+	-	-	+	+	-	-
Malaysia	-	+	-	+	-	-	+	-	+	-
Philippines	+	+	+	-	+	-	+	-	-	+
Sawnwood--										
Japan	-	-	-	-	-	-	-	-	-	-
Indonesia	-	+	-	-	+	+	+	+	+	+
Malaysia	+	-	+	-	+	+	-	+	-	-
Philippines	+	-	-	+	-	+	+	+	+	+
Plywood--										
Japan	-	-	-	-	-	-	-	+	+	-
Indonesia	-	+	-	-	+	+	-	-	+	+
Malaysia	+	-	+	-	+	+	-	+	-	+
Philippines	+	-	-	+	+	+	+	-	-	+
Total surplus:										
Japan	+	-	-	-	-	-	+	+	+	+
Indonesia	+	-	+	+	+	-	+	+	-	-
Malaysia	-	+	-	+	+	-	+	-	+	-
Philippines	+	+	+	-	+	-	+	-	-	+

1/ Increase (+) or decrease (-) compared with results of baseline simulation.

2/ A = Actual data; B = baseline simulation; 1 = free trade (no tariffs); 2 = Indonesian log-export embargo; 3 = Malaysian log-export embargo; 4 = Philippine log-export embargo; 5 = South Seas log-export embargo; 6 = 100-percent log-export surcharge by South Seas nations; 7 = Japanese yen 10 percent stronger; 8 = Indonesian rupiah 10 percent weaker; 9 = Malaysian ringgit 10 percent weaker; 10 = Philippine peso 10 percent weaker.

The changes to the model necessary for carrying out the simulations were easy to implement. The computer code for the reactive-programming algorithm includes a file containing input data. Within this file, data used in the price linkages represented by equation (1) were altered appropriately for each simulation. For simulation 1, export duties by the South Seas nations and import tariffs by Japan were removed. I will call this simulation the free-trade simulation, even though import barriers by the South Seas nations, which were represented by very large transfer costs, were not removed. For simulations 2-5, transfer costs for log trade were made prohibitively high to prevent log exports. For simulation 6, log-export duties by the South Seas nations were increased by 100 percent. For simulations 7-10, exchange rates were modified to represent changes in the relative strengths of the four currencies.

Results: Log-Export Embargoes

Log-export embargoes have been either contemplated or implemented by every nation in the South Seas. The consequences of single-nation embargoes, represented by simulations 2-4, followed very similar patterns. Changes in domestic prices and quantities are not shown but can be summarized as follows. Log prices decreased markedly in the nation erecting the embargo (the home nation) and increased elsewhere. The log-price increase in other South Seas nations was due to Japan's demand for logs being concentrated on fewer suppliers. Because of these price changes, log consumption in the manufacture of sawnwood and plywood increased in the home nation, whereas log production decreased; elsewhere, production increased, and consumption decreased. The lower log prices in the home nation induced its sawnwood and plywood prices to decrease, causing domestic consumption of these processed products to increase. Despite lower prices of sawnwood and plywood, domestic processing also increased because lower log prices offset the lower prices of processed products and led to higher profits for processors. In the other regions, prices of processed products increased because of higher log prices, and the higher prices made these products less competitive in the Japanese import market than the home nation's processed products. Comparing column B with columns 2-4 in table 4 shows that the home-nation's exports of processed products to Japan increased.

The welfare effects of the embargoes were studied by considering changes in consumer and producer surplus for each product in each nation. "Consumer surplus" is defined as the area under a demand curve and above the equilibrium price line. This represents the extra amount consumers would be willing to pay for the goods they purchase. "Producer surplus" is the area above a supply curve and under the equilibrium price line. This represents rents to the fixed factors of production. Because demand and supply curves in JIMP are linear, these surpluses were easily calculated from the formula for the area of a triangle. I calculated changes in welfare by subtracting the areas of the triangles in the baseline case from the corresponding areas in each simulation.

Results are given in table 5. A "plus" sign indicates that the value of the welfare measure increased in the particular simulation; a "minus" sign that it decreased. Consumer surplus for logs is not included in the total surplus because it is a component of consumer surplus for the processed products. Table 5 shows that the nation imposing a log-export embargo suffered a loss in total surplus, as did Japan. The sole cause of the welfare loss in the home nation was the loss in log-producer surplus, which outweighed the gains in total surplus for sawnwood and plywood. These welfare changes represent a transfer of wealth from the government to the private sector because forests are owned by the governments of the South Seas nations, whereas processing facilities tend to be owned by the private sector. Note that this welfare loss is a static (single-period) result; over a longer period, an embargo might have positive welfare effects if, for example, it induced large increases in domestic processing.

In contrast, table 5 shows that an embargo imposed by the three South Seas nations simultaneously (simulation 5) produced a positive change in welfare for all three nations; Japan again lost. Production of tropical sawnwood and plywood in Japan dropped to zero because Japan could not acquire tropical logs. As a consequence, trade flows of processed products to Japan increased markedly (table 4). As might be expected, the South Seas embargo produced dramatic price changes, not shown. For example, the price of plywood increased 130 percent in Japan. In the real world, such a large price increase would probably induce substitution of plywood from other sources. At present, JIMP cannot measure this substitution because it does not include plywood made from logs other than from the South Seas.

Results: Changes in Exchange Rates

Simulations 7-10 in table 5 show the results of changes in exchange rates. These results must be interpreted with caution because exchange rates in JIMP, as in other forest-product-trade models, affect only the relative prices of traded goods. In the real world, however, exchange rates affect many elements of an economic system. They affect many of the variables treated as exogenous in demand and supply equations, such as gross domestic product, interest rates, and price index (which in turn affects wage rates). Simulation scenarios that modify exchange rates without also modifying other exogenous variables affected by them are inconsistent.

Like simulations of other forest products trade models, simulations 7-10 are guilty of this charge.[2] Nevertheless, the simulation results have value as indicators of the potential magnitude of exchange-rate effects. Table 4 is most useful for studying these effects. Under simulation 7, strengthening of the yen, Japanese imports of logs decreased whereas imports of processed products increased. The size of the increased trade flows of processed products is comparable to that in simulation 1, free trade, and simulation 6, a 100-percent log-export surcharge. Table 5 shows that all nations gained in welfare as a result of the stronger yen. Japanese sawnwood and plywood producers lost, but the gains by consumers outweighed these losses.

The patterns observed in simulations 8-10, weakening of individual South Seas currencies, show some variation. Table 4 shows that devaluation of the Indonesian rupiah and the Philippine peso decreased log flows to Japan but increased flows of processed products. When the Malaysian ringgit was devalued, on the other hand, Japanese imports of products processed in Malaysia did not increase, but imports of logs did. Table 5 shows that in each case Japan and the nation devaluing its currency gained in welfare, and the other two nations suffered losses.

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[2] The IIASA model considers the effects of exchange rates on production costs, through the prices of imported factors of production. It does not, however, consider how exchange rates affect demand.

Conclusions

The estimation and validation of JIMP are preliminary. The research results presented in this paper do demonstrate, however, that trade in the Pacific basin can be analyzed in a supply-and-demand, spatial-equilibrium framework. This framework can be used to study policy issues such as trade barriers and changes in exchange rates.

Results of static simulations for 1980 indicate that South Seas nations will benefit from a log-export embargo only if they act together. A dynamic model might not produce this finding, however. Other results suggest that relatively small changes in exchange rates affect trade patterns nearly as much as does the dismantling of all trade barriers (except those between South Seas nations) or the imposition of very large export surcharges on logs. Model results indicate that all nations gain from a stronger yen.

Confidence in simulation results of JIMP would be increased by further research in the following areas. First, specification of several equations could be improved—the Japanese sawnwood equation, for example. Second, the model should be solved for additional periods to permit more extensive validation and investigation of dynamic effects. Third, the effects of changes in exchange rates on macroeconomic variables should be accommodated by developing sets of exogenous variables consistent with different exchange rates. Finally, data from sources other than the "Yearbook," specifically sources from within the South Seas nations themselves, should be sought. Better data exist, but they can be accessed only by doing research in the nations themselves or by establishing cooperative links with researchers in those nations. These data should be compared with the "Yearbook" and "Japan Lumber Journal" data to determine, for example, whether f.o.b. and c.i.f. prices are similar to domestic prices and whether residually calculated transfer costs approximate actual transfer costs.

A more ambitious goal would be to construct a model that includes both hardwood and softwood products, to study more readily the substitution possibilities between South Seas and North American products. If South Seas nations further restrict log exports, Japan's $4 billion (1983) market for products made from South Seas logs will probably become more open to competing products.

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Appendix 1. Data

This appendix gives more information on the data used in estimating and simulating the model. Tables 6-11 give the actual data series used. Headings of these tables are defined in "Abbreviations of Variables." Note that all prices in these tables are nominal.

South Seas Nations

The "Yearbook" was the primary data source for Indonesia, Malaysia, and the Philippines. It contains data on production, total exports, total imports, and f.o.b. and c.i.f. unit values. Apparent consumption of all products was calculated by adding production and imports and subtracting exports. All series for sawnwood and plywood were accepted without modification. Log-production figures were modified for Indonesia and the Philippines, however, for years in which recovery rates seemed abnormally high (>0.7) or low (<0.3). Recovery rates were calculated as:

$$\frac{\text{Sawnwood production} + \text{plywood production}}{\text{Log production} + \text{log imports} - \text{log exports}} .$$

Abnormal recovery rates were excluded from the calculated recovery rate series, and replacements were created from regressions of the remaining rates on a trend variable and a constant. These new recovery rates were then used with the data on log exports, log imports, and sawnwood and plywood production to solve for new log-production figures.

I used average annual exchange rates given in "International Financial Statistics," published annually by the International Monetary Fund, to convert unit values from U.S. dollars to domestic currencies. Producer prices were assumed to be equal to f.o.b. unit values. Consumer prices were calculated as weighted averages of f.o.b. and c.i.f. unit values; the weight for f.o.b. unit values was domestic production minus export quantity, and the weight for c.i.f. unit values was quantity of imports. The consumer prices calculated this way did not differ much from producer prices because the South Seas nations import only small amounts of forest products. The use of f.o.b. unit values probably introduced an upward bias into assumed domestic prices because the nations tend to export the more highly valued portion of production.

The f.o.b. unit values were, except for the Philippines, assumed to be net of tariffs. Because transfer costs for Philippines-Japan log trade calculated from the "Yearbook" values were too low, new f.o.b. unit values were created—the values listed in the "Yearbook" were divided by 1.25 to account for the Philippine's 25-percent export duty.

Japan

Data for Japan were gathered from a variety of sources. Because only tropical products were included in the model, Japanese log production figures were not necessary. Furthermore, exports of logs, sawnwood, and plywood could be ignored because they were less than 1 percent of consumption (logs) or production (sawnwood and plywood) for most years. Quantity data series were needed only for imports of all products, consumption of logs for sawnwood and plywood, and production and consumption of sawnwood and plywood.

Data on Japanese imports from the individual South Seas nations were taken from annual summary tables published in various issues of the "Japan Lumber Journal" ("Journal"). Data on log and sawnwood imports were used directly. The plywood data had to be converted from square meters to cubic meters by use of the ratio of aggregate plywood imports given in the "Yearbook" (in cubic meters) to the same series given in the "Journal" (in square meters).

The "Journal" import data differ from export data for South Seas nations given in direction-of-trade tables in the "Yearbook." That the volume of a bilateral trade flow should differ at point of export and point of import is not surprising because transport lags cause dates of export and import to differ and because both export and import figures suffer from reporting error. Reporting errors can be quite serious; official Philippine log-export figures have been estimated to understate true exports by as much as 300 percent (Foreign Agricultural Service 1985). Consistency, in the sense of imports equaling exports, was achieved in the JIMP data set by assuming that the import figures for Japan from the "Journal" and the total export figures for the South Seas nations from the "Yearbook" were correct. Trade flows to the rest of the world were then determined residually.

Japanese consumption of logs for sawnwood and plywood was given in the "Journal." These figures were measured by log arrivals at mills. Log arrivals did not always sum to annual total log imports, reflecting the lag time between unloading at the dock and delivery to the mill. The discrepancies were not great, and I eliminated them by adjusting the data on logs consumed for plywood. Production data for tropical sawnwood and plywood were created from log-consumption data and annual recovery rates for total sawnwood and total plywood production (based on "Yearbook" data). I assumed that the recovery rates for products made from tropical wood were the same as those for products made from other hardwoods. The production figures added to the sum of imports from Indonesia, Malaysia, and the Philippines determined consumption of tropical products.

Log price in Japan was assumed to be equal to the weighted average of log-import unit values from the South Seas, given in yen per cubic meter in the "Journal." Trade prices were not used for sawnwood and plywood. Sawnwood price was assumed to be equal to the wholesale price of lauan sawnwood boards of dimensions 3.0-3.4 cm by 30.0 cm by 4.0 m, given in yen per cubic meter and listed in various issues of the "Monthly Report of Japan Timber Market." Plywood prices were volume-weighted averages of Tokyo wholesale prices of plywood of various thicknesses. Plywood price and production data were taken from the "Journal" for 90-by-180-cm sheets that were 2.5, 4.0, and 12.0 mm thick. The aggregate price was converted to yen per cubic meter by use of "Yearbook" and "Journal" data on production.

Abbreviations of Variables

Most headings in tables 6-11 and most variables in the equations in appendix 2 are named according to a consistent system of abbreviations. The first letter represents the nation where production or consumption takes place:

J = Japan

I = Indonesia

M = Malaysia

P = Philippines.

The second letter represents the product being produced or consumed:

L = log

S = sawnwood

P = plywood.

The third letter represents the type of economic activity:

P = production

C = consumption

E = export

I = import.

The fourth letter represents the type of economic variable:

P = price

Q = quantity.

If the fourth letter is P, the addition of R as a fifth letter indicates that price is in real terms; the addition of the letter A indicates that price is in United States dollars. For example, MLEP denotes the Malaysian log-export price in nominal terms, whereas MLEPR denotes the same price series in real terms. For Japanese imports (that is, the first letter is J and the third letter is I), the addition of a fifth letter indicates the source of the import—I (Indonesia), M (Malaysia), or P (Philippines). For example, JLIQI denotes Japanese log-import quantity from Indonesia.

Exceptions to this system are names for the exogenous (shift) variables:

JGDP = Japanese gross domestic product in billion yen. IGDP, MGDP, PGDP, and ROWGDP are defined similarly and are in billion rupiahs, million ringgits, million pesos, and billion dollars, respectively. An R added as a fifth letter to a GDP variable indicates that the variable is in real terms.

JGDPC = absolute change in nominal Japanese GDP from one period to the next.

JHOUSE = Japanese housing starts, in thousands.

JPPI = Japanese producer price index (1980 = 1.000). IPPI, MPPI, and PPPI are defined similarly.

JOIL = Japanese oil price index (1980 = 1.000). IOIL, MOIL, and POIL are defined similarly. An R added as a fifth letter to an OIL variable indicates that the variable is in real terms. A C added as a fifth letter to an OIL variable or as a sixth letter to an OILR variable indicates that the variable represents the percentage change in the oil price index from one period to the next.

JAEXCH = Japan-U.S. exchange rate, in yen per dollar. IAEXCH, MAEXCH, and PAEXCH are defined similarly.

DUM79 = Dummy variable, equal to 1 in all years up to and including 1979 and equal to 0 in all years after 1979. Dummy variables for other years are defined similarly.

DUMX79 = Dummy variable, equal to 1 in 1979 and equal to 0 in all other years. Dummy variables for other years are defined similarly.

Table 6—Data on log imports in Japan[1]

	Quantity			Price		
Year	JLIQI	JLIQM	JLIQP	JLIPI	JLIPM	JLIPP
	Thousand cubic meters			Yen/cubic meter		
1970	5936	6018	7859	10687	10687	12021
1971	8531	5963	6292	10544	10563	12203
1972	8916	6903	5223	9141	8946	9698
1973	11331	8447	6136	14732	14169	14027
1974	12168	8050	4073	18830	17823	19926
1975	7424	6567	3071	14393	13231	15119
1976	9680	10108	1902	20788	19764	21576
1977	9615	9552	1664	19736	18013	22742
1978	9218	10518	1805	16162	15084	18629
1979	9977	10718	1400	33362	31514	32849
1980	8905	8373	1166	35342	32680	39958
1981	4507	8373	1467	29301	25774	30713
1982	2715	10261	1446	36243	31399	34631
1983	2217	10468	706	29596	25136	29574

1/ Headings are explained in "Abbreviations of Variables" in appendix 1.

Table 7—Data on products processed in Japan[1]

	Quantity				Price	
	Sawnwood		Plywood		Sawnwood	Plywood
Year	JSPQ	JSCQ	JPPQ	JPCQ	JSCP	JPCP
	Thousand cubic meters				Yen/cubic meter	
1970	5743	5981	6558	6560	42300	51721
1971	6408	6652	6819	6819	43000	41349
1972	6612	6834	7320	7325	40800	44618
1973	7982	8312	8164	8216	57400	72824
1974	7239	7678	7105	7114	73200	57891
1975	6314	6430	5796	5797	66800	48432
1976	6529	6694	6815	6815	76000	57313
1977	4117	4373	7143	7144	82200	57000
1978	5439	5717	7866	7872	79500	51291
1979	5894	6267	8200	8209	113300	75909
1980	4347	4863	7665	7697	144400	82461
1981	3686	4049	6756	6772	127700	66425
1982	3061	3642	6466	6476	135900	72371
1983	2816	3434	6949	6971	129400	67998

1/ Headings are explained in "Abbreviations of Variables" in appendix 1.

Table 8—Data for Indonesia[1]

	Quantity						Price		
	Logs		Sawnwood		Plywood		Logs	Sawnwood	Plywood
Year	ILPQ	ILCQ	ISPQ	ISCQ	IPPQ	IPCQ	ILEP	ISEP	IPEP
	Thousand cubic meters						Rupiahs/cubic meter		
1970	10700	2866	1662	1618	NA	NA	4015	12443	NA
1971	13705	2883	1662	1582	7	10	5945	13293	NA
1972	16821	3467	1662	1555	4	9	7094	8544	NA
1973	21190	2690	1380	1050	9	23	12591	20351	NA
1974	20377	3504	1819	1542	24	38	17289	32843	NA
1975	17212	4787	2400	2007	107	113	13066	33052	26560
1976	23200	5505	3000	2352	214	206	18421	31181	27677
1977	25368	6808	3500	2906	279	266	19491	35089	52167
1978	26620	7420	3500	2744	424	358	20502	50081	115767
1979	24860	7060	3400	2117	624	508	52439	114193	168929
1980	23637	8753	3975	2772	1014	771	62111	134523	142638
1981	19312	13111	5750	4579	1723	965	59022	101779	122947
1982	19394	16290	6798	5576	2487	1256	66511	99724	151536
1983	19544	16551	6296	4913	3138	1384	90084	140674	225397

NA = not available.

1/ Headings are explained in "Abbreviations of Variables" in appendix 1.

Table 9—Data for Malaysia[1]

	Quantity						Price		
	Logs		Sawnwood		Plywood		Logs	Sawnwood	Plywood
Year	MLPQ	MLCQ	MSPQ	MSCQ	MPPQ	MPCQ	MLEP	MSEP	MPEP
	Thousand cubic meters						Ringgits/cubic meter		
1970	18658	7328	3100	1773	197	58	57	148	354
1971	18457	7408	3098	1819	231	44	56	144	316
1972	20713	9372	3738	2037	330	68	56	155	316
1973	23599	10882	4293	2209	375	28	75	259	453
1974	21492	9345	4043	2131	311	101	85	249	498
1975	18972	8208	3851	2200	404	175	62	226	461
1976	26585	11102	5128	2266	525	122	93	290	466
1977	27579	11494	5654	2907	565	229	95	285	477
1978	28504	11821	5913	3286	465	70	99	289	478
1979	28516	12060	NA	NA	490	46	183	379	625
1980	28516	13370	NA	NA	601	149	173	404	620
1981	30317	14451	NA	NA	603	167	153	352	661
1982	32482	13192	NA	NA	787	417	175	373	599
1983	33300	14505	NA	NA	NA	NA	174	396	569

NA = not available.

1/ Headings are explained in "Abbreviations of Variables" in appendix 1.

Table 10—Data for the Philippines[1]

Year	Quantity						Price		
	Logs		Sawnwood		Plywood		Logs	Sawnwood	Plywood
	PLPQ	PLCQ	PSPQ	PSCQ	PPPQ	PPCQ	PLEP	PSEP	PPEP
	Thousand cubic meters						Pesos/cubic meter		
1970	13836	4230	1341	1156	653	392	150	356	575
1971	11632	3189	861	630	642	364	170	327	631
1972	10446	3588	1412	1181	732	415	168	426	718
1973	11505	3746	1061	634	705	317	264	555	1028
1974	7332	2639	1292	1008	274	103	312	718	1093
1975	8441	3845	1470	1216	423	266	263	777	951
1976	8646	6315	1609	1116	416	156	431	1029	1235
1977	7873	5826	1567	1112	489	149	387	1084	1217
1978	7169	4969	1781	1208	490	107	388	1095	1436
1979	6578	5330	1626	711	515	98	683	1599	1994
1980	6212	5058	1529	787	553	186	775	1834	2400
1981	5280	3597	1219	672	463	65	682	1816	2352
1982	4462	2872	1200	609	434	185	710	1787	2377
1983	4283	3266	1222	494	469	166	835	2275	2877

1/ Headings are explained in "Abbreviations of Variables" in appendix 1.

Table 11—Data on exchange rates and price indexes[1]

Year	Exchange rates				Price indexes			
	JAEXCH	IAEXCH	MAEXCH	PAEXCH	JPPI	IPPI	MPPI 2/	PPPI
	Foreign currency/U.S. dollar				1980 = 1.000			
1970	358	365	3.08	5.91	0.484	0.185	0.506	0.213
1971	347	393	3.02	6.43	.480	.194	.504	.247
1972	303	415	2.80	6.67	.484	.181	.505	.284
1973	271	415	2.44	6.76	.560	.251	.596	.345
1974	292	415	2.41	6.79	.737	.370	.671	.521
1975	296	415	2.40	7.25	.759	.393	.651	.533
1976	296	415	2.54	7.44	.797	.433	.733	.586
1977	268	415	2.46	7.40	.812	.480	.784	.652
1978	210	442	2.32	7.37	.791	.527	.824	.702
1979	219	623	2.19	7.38	.849	.767	.938	.841
1980	226	627	2.18	7.51	1.000	1.000	1.000	1.000
1981	220	631	2.30	7.90	1.014	1.114	1.027	1.131
1982	249	661	2.34	8.54	1.032	1.188	1.047	1.252
1983	237	909	2.32	11.11	1.009	1.405	1.094	1.450

1/ Headings are explained in "Abbreviations of Variables" in appendix 1.
2/ Gross domestic product deflator, not producer price index.

Appendix 2. Estimation

General Remarks

The full set of estimated equations used in the model are listed at the end of this appendix. In general, coefficients were accepted if they were significant at the 10-percent level, although coefficients significant at higher levels were occasionally accepted. The Durbin-Watson statistic was used to test for autocorrelation, even in equations with lagged endogenous variables. Because this statistic is biased toward 2 under the latter conditions, sometimes autocorrelation may have been present but was not detected. When autocorrelation was detected (rejection of the hypothesis of no positive autocorrelation at the 5-percent level), the Cochrane-Orcutt correction was performed. If the correction produced coefficients with the correct signs and significant t-statistics, and the original equation was acceptable for reasons other than the low Durbin-Watson statistic, the original coefficients were accepted. This was done to preserve degrees of freedom: autocorrelation does not affect consistency of estimates, but the correction does use up one degree of freedom.

In some equations, dummy variables were used to account for especially large residuals (outliers). These dummies were set equal to one for the year in question and zero for all other years. Dummies were used sparingly, no more than one per equation because their explanatory power is weak. If a data set is reliable, a correctly specified equation should have no dummy variables.

Special problems were confronted in estimating certain equations. In the Japanese plywood demand equation, a specification in which the coefficient on price was correctly signed and significant was not found. This indicated that plywood demand was totally inelastic with regard to price. Nomura and Yukutake (1982) and Yoshida (1982) encountered similar difficulties, reporting coefficients with correct signs but t-statistics of only 0.0682 (36 observations) and 1.0269 (25 observations). The solution adopted in JIMP was to restrict the plywood price elasticity to that reported by Wibe (1984) for panel products in nations with incomes greater than $2,500 per capita, -0.18.

Getting a satisfactory coefficient on log price was a problem with the Indonesian and Malaysian sawnwood and plywood supply equations. Without such a term, derived log-demand equations have no price responsiveness. The solution adopted was to restrict the log-price elasticities in the Indonesian and Malaysian sawnwood and plywood supply equations to the values in the Philippine supply equations: about 0.94 and 0.59, respectively.

Estimated Equations

In this section, I list all econometrically estimated equations included in JIMP. Definitions of variables are given in "Abbreviations of Variables" in appendix 1. Coefficients associated with each variable are given, and the " t " statistic of each coefficient is given in parentheses under the coefficient. A missing " t " statistic indicates that the coefficient was constrained to equal an exogenous value. Standard information about each equation (period of estimation, R-squared, standard error of the regression, Durbin-Watson statistic) is also given.

Log Supply Equations

Indonesia: $ILPQ = 0.223 * ILEPR + 0.628 * ILPQ(-1) - 6496 * DUM79$

(3.73) (4.90) (4.48)

1970-83, $R^2 = 0.843$, S.E.R. = 1949, D-W = 1.55

Malaysia: $MLPQ = 69.3 * MLEPR + 0.685 * MLPQ(-1) - 7429 * MOILRC$

(2.49) (4.49) (2.68)

1970-83, $R^2 = 0.879$, S.E.R. = 1956, D-W = 2.13

Philippines: $PLPQ = 5.92 * PLEP - 9094 * PPPI - 2680 * POILC \quad 1845 * DUMX71 + 11912$

(3.44) (8.21) (3.21) (4.11) (39.0)

1970-83, $R^2 = 0.972$, S.E.R. = 406, D-W = 1.62

Log Demand Equations

ROW for Indonesia:

$ILEQROW = -74.8 * ILEPA + 7.09 * ROWGDP - 5.78 * ROWGDP(-1) + 0.381 * ILEQROW(-1) + 3186 * DUMX76$

(3.46) (3.97) (3.12) (2.40) (2.86)

1970-83, $R^2 = 0.924$, S.E.R. = 1050, D-W = 1.65

ROW for Malaysia:

$MLEQROW = -38.3 * MLEPA + 1.23 * ROWGDP(-1) - 1640 * DUMX75 + 3067$

(1.83) (4.11) (2.17) (6.31)

1970-83, $R^2 = 0.843$, S.E.R. = 689, D-W = 1.73

ROW for Philippines:

$PLEQROW = -9.86 * PLEPA - 821 * DUM74 + 689 * DUMX80 + 2076$

(2.78) (3.35) (1.92) (11.6)

1970-83, $R^2 = 0.861$, S.E.R. = 293, D-W = 2.69

Sawnwood Supply Equations

Japan:

$$\text{JSPQ} = \underset{(1.36)}{0.0242*\text{JSCP}} - \underset{(3.41)}{6104*\text{JOIL}} - \underset{(2.04)}{1516*\text{DUMX77}} + \underset{(11.2)}{7150}$$

1970-83, $R^2 = 0.843$, S.E.R. = 717, D-W = 0.68

Indonesia:

$$\text{ISPQ} = \underset{(4.84)}{0.0277*\text{ISEPR}} - \underset{(\text{NA})}{0.0680*\text{ILEPR}} + \underset{(8.53)}{1.32*\text{ISPQ}(-1)}$$

1970-83, $R^2 = 0.891$, S.E.R. = 853, D-W = 1.43

Malaysia

$$\text{MSPQ} = \underset{(2.69)}{8.23*\text{MSEPR}} - \underset{(\text{NA})}{30.4*\text{MLEPR}} - \underset{(6.42)}{0.987*\text{MSPQ}(-1)} - \underset{(2.85)}{1289*\text{DUMX75}} + \underset{(1.78)}{1201}$$

1965-78, $R^2 = 0.948$, S.E.R. = 429, D-W = 1.80

Philippines

$$\text{PSPQ} = \underset{(7.95)}{1.72*\text{PSEPR}} - \underset{(3.86)}{2.01*\text{PLEPR}} - \underset{(2.11)}{166*\text{DUM79}}$$

1970-83, $R^2 = 0.745$, S.E.R. = 136, D-W = 2.24

Sawnwood Demand Equations

Japan:

$$\text{JSCQ} = \underset{(6.71)}{-0.0329*\text{JSCP}} + \underset{(4.05)}{0.178*\text{JGDPC}} - \underset{(3.38)}{2329*\text{DUMX77}} + \underset{(8.05)}{6095}$$

1970-83, $R^2 = 0.859$, S.E.R. = 644, D-W = 2.42

Indonesia:

$$\text{ISCQ} = \underset{(5.75)}{-0.0262*\text{ISEP}} + \underset{(11.2)}{0.107*\text{IGDP}} + \underset{(11.1)}{1454}$$

1970-83, $R^2 = 0.961$, S.E.R. = 301, D-W = 1.45

Malaysia

$$\text{MSCQ} = \underset{(1.84)}{-2.38*\text{MSCPR}} + \underset{(7.60)}{0.0830*\text{MGDPR}} - \underset{(2.06)}{349*\text{DUM74}} + \underset{(1.96)}{544}$$

1965-78, $R^2 = 0.952$, S.E.R. = 155, D-W = 2.27

Philippines

$$\text{PSCQ} = \underset{(4.02)}{-0.469*\text{PSEP}} + \underset{(2.86)}{455*\text{DUM74}} + \underset{(10.5)}{1096}$$

1970-83, $R^2 = 0.595$, S.E.R. = 186, D-W = 2.87

Plywood Supply Equations

Japan:

$$\mathrm{JPPQ} = 0.0473*\mathrm{JPCP} - 0.0704*\mathrm{JLIP} - 2646*\mathrm{JOILC} + 0.862*\mathrm{JPPQ}(-1) - 1113*\mathrm{DUMX75}$$

(2.41) (2.59) (2.79) (6.99) (2.17)

1970-83, $R^2 = 0.683$, S.E.R. = 459, D-W = 1.53

Indonesia:

$$\mathrm{IPPQ} = 0.00437*\mathrm{IPEPR} - 0.0134*\mathrm{ILEPR} + 1.46*\mathrm{IPPQ}(-1)$$

(4.04) (NA) (10.2)

1975-83, $R^2 = 0.930$, S.E.R. = 340, D-W = 1.19

Malaysia:

$$\mathrm{MPPQ} = 0.393*\mathrm{MPEPR} - 1.93*\mathrm{MLEPR} + 0.983*\mathrm{MPPQ}(-1) + 175*\mathrm{DUM79}$$

(3.78) (NA) (5.26) (2.66)

1970-82, $R^2 = 0.856$, S.E.R. = 86, D-W = 2.23

Philippines:

$$\mathrm{PPPQ} = 0.370*\mathrm{PPEPR} - 0.458*\mathrm{PLEPR} - 228*\mathrm{DUMX74}$$

(9.85) (3.51) (6.02)

1970-83, $R^2 = 0.929$, S.E.R. = 37, D-W = 2.70

Plywood Demand Equations

Japan:

$$\mathrm{JPCQ} = -0.0159*\mathrm{JPCPR} + 3.45*\mathrm{JHOUSE} + 0.467*\mathrm{JPCQ}(-1) + 570*\mathrm{DUM78} - 1195*\mathrm{DUMX75}$$

(NA) (8.05) (4.66) (2.16) (2.93)

1970-84, $R^2 = 0.857$, S.E.R. = 364, D-W = 2.27

Indonesia:

$$\mathrm{IPCQ} = -0.000998*\mathrm{IPCP} + 0.0242*\mathrm{IGDP} - 130*\mathrm{DUM74}$$

(2.09) (16.0) (3.35)

1971-83, $R^2 = 0.987$, S.E.R. = 60, D-W = 1.72

Malaysia:

$$\mathrm{MPCQ} = -0.417*\mathrm{MPCP} + 0.0138*\mathrm{MGDP} - 292*\mathrm{DUM78}$$

(2.56) (4.34) (3.54)

1970-82, $R^2 = 0.732$, S.E.R. = 60, D-W = 1.96

Philippines:

$$\mathrm{PPCQ} = -0.136*\mathrm{PPEPR} - 309*\mathrm{DUM74} + 739$$

(1.94) (5.86) (3.88)

1970-83, $R^2 = 0.851$, S.E.R. = 49, D-W = 2.76

ROW for Indonesia:

$$\mathrm{IPEQROW} = -0.978*\mathrm{IPEPA} + 0.192*\mathrm{ROWGDP}(-1) + 1.07*\mathrm{IPEQROW}(-1) - 210*\mathrm{DUMX80} - 568$$

(2.72) (6.31) (14.1) (2.97) (5.29)

1975-83, $R^2 = 0.996$, S.E.R. = 59, D-W = 3.00

Vincent, Jeffrey R. 1987. Modeling Japan-South Seas trade in forest products. Gen. Tech. Rep. PNW-GTR-210. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 28 p.

The international trade of forest products has generated increasing research interest, yet experience with modeling such trade is limited. Primary issues include the effects of trade barriers and exchange rates on trade patterns and national welfare. This paper attempts to add to experience by modeling hardwood log, lumber, and plywood trade in a region that has been mostly overlooked: East Asia, specifically Japan and the South Seas nations (Indonesia, Malaysia, and the Philippines). Japan-South Seas trade is important because of its significance in global forest-products trade and because of the large changes in trade barriers and exchange rates since 1970. In this paper, I describe the development of an economic model, JIMP, for investigating trade issues in the region. The model uses reactive programming to solve for a spatial equilibrium. Preliminary results suggest that: (1) restrictions on log exports will benefit South Seas nations only if the nations act together, and (2) relatively small fluctuations in exchange rates influence trade patterns as much as do large changes in tariffs.

Keywords: Trade modeling, Japan, South Seas nations, hardwood products, trade barriers, exchange rates, spatial equilibrium, reactive programming.

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